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Western Operations Office

REON

SACRAMENTO PLANT

REPORT NO. RN-S-0220

TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

ASSEMBLY AND BRAZING OF NERVA U-TUBE NOZZLES (U)

NERVA PROGRAM CONTRACT SNP-1

OCTOBER 1965

AEROJET GENERAL TIRE GENERAL

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

C66-6???

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ROCKET ENGINE OPERATIONS — NUCLEAR

NERVA PROGRAM

CONTRACT SNP-1

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ABSTRACT

This report describes the development of assembly and furnace brazing procedures for NERVA (Nuclear Engine Rocket Vehicle Application) regeneratively cooled hydrogen expansion nozzles using the "U" Tube design. Braze alloy selection, test program results, special tool designs and actual component assembly techniques are presented. The test program using full length nozzle sections, qualified by hydro tests, and full scale hardware subjected to chemical and nuclear firings indicate that if appropriate assembly and furnace brazing procedures are used satisfactory results can be obtained.

Prepared by H.W. Spaletta and D. M. Hamilton.

for W. D. Stinnett
Technical Systems Manager
REON

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I. INTRODUCTION

I. INTRODUCTION

Fabrication problems with the cast aluminum jacket nozzle made it the pacing item of the NERVA Program. Because of this fact, Aerojet management decided to produce two articles using the U-tube forged jacket design. One would be assembled at AGC-LRP; and the other would be subcontracted to the Marquardt Corporation, Ogden, Utah. The purpose of the program presented here was to select acceptable braze alloys and develop assembly procedures for the NERVA U-Tube design nozzles.

In conventional assemblies, light-weight closed coolant tubes are furnace-brazed to effect a hot gas seal between the tubes (Figures 1 and 2). The resulting joints are not primary load carrying joints (Figure 1-C and 2-C). Braze alloys used for the conventional AGC thrust chambers contain temperature depressants - such as boron, silicon, and/or carbon which affect the alloy flow points. These alloys are sensitive to minor chem ical variations. Braze alloy powder is applied between the tube OD's, and the assemblies are furnace-brazed using comparatively fast rates of heating and cooling (Reference 1).

In contrast, the U-Tube nozzle design requires on internal tube-to-groove shear joint which carries the primary load of the coolant pressure (Figure 3). The tubes, formed to the open channel configuration, are 0.014-in. thick and are furnace brazed to the internal wall of a forged shell having a minimum thickness of 0.5 in. The shell-to-tube thickness ratio at 35-to-1 requires a controlled rate of heating and cooling to prevent distortion and joint rupture during the braze cycle. The U-Tube configuration also requires the use of measured amounts of braze alloy foil and/or wires preplaced adjacent to the interior shear joints.

A program was initiated to develop assembly and furnace-brazing procedures (Reference 2) using ductile braze alloys foil configurations. The Marquardt Corporation was instructed to initiate a program similar to, but independent of, AGC's program. The Marquardt Corporation fabricated NERVA Nozzle S/N-8 and AGC fabricated NERVA Nozzle S/N-9 and S/N's 21 through 28 during the initial period.

Note:

The assistance given by Frank Bell (AGC-LRP) Arndt Fortlage (Pyromet, San Carlos), Jack Eyres (AGC, Source Inspection) Ed Franco-Ferrori (ORNL) for guidance and close support during this program is acknowledged.

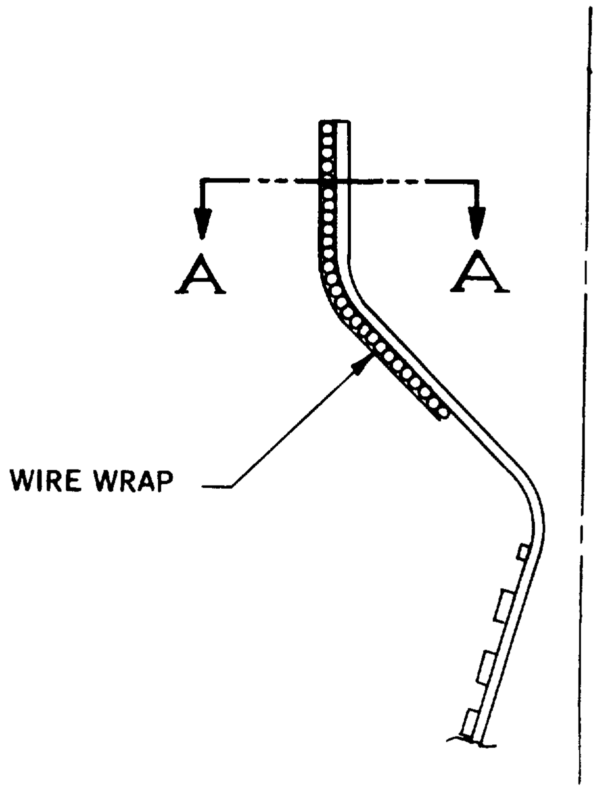


FIGURE A
TITAN THRUST CHAMBER

SECTION A-A

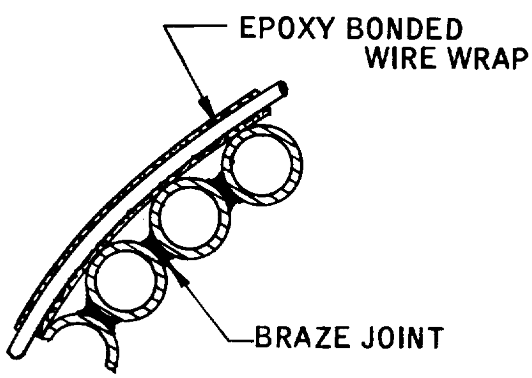


FIGURE B
SHOWING FURNACE BRAZED JOINT
FOR THE TITAN THRUST CHAMBER

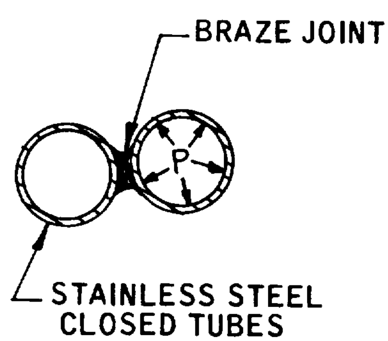


FIGURE C
INTERNAL PRESSURE LOADING
ON TITAN TUBES

Figure 1

Titan Thrust Chamber Tubes

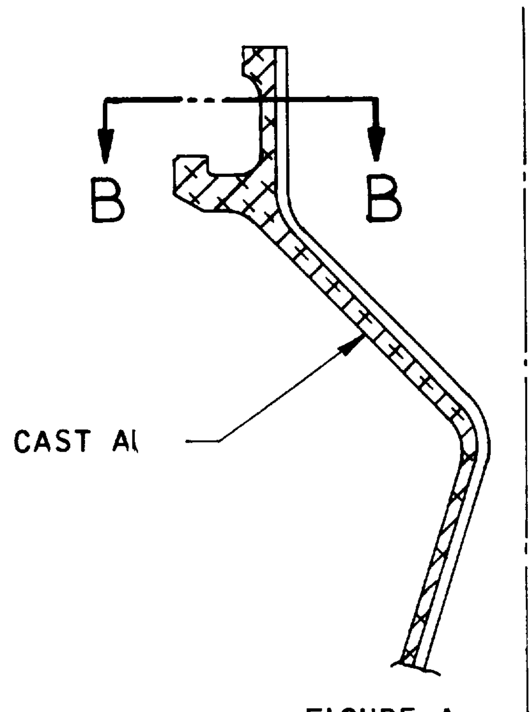


FIGURE A
Al CAST NERVA NOZZLE

SECTION B-B

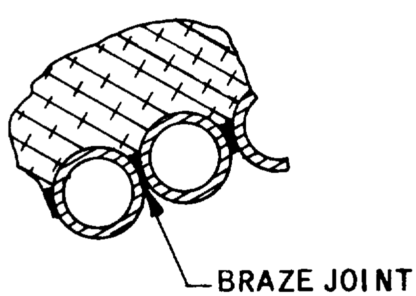


FIGURE B
SHOWING FURNACE BRAZE JOINT
FOR THE Al CAST NERVA NOZZLE

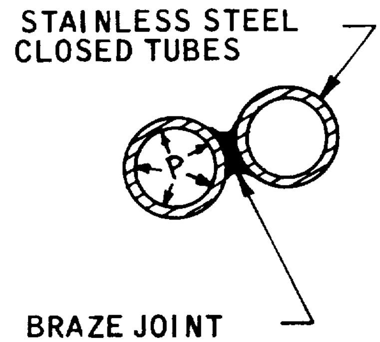


FIGURE C
INTERNAL PRESSURE LOADING ON Al CAST
JACKET NERVA TUBES

Figure 2

Al. Cast NERVA Nozzle Tubes

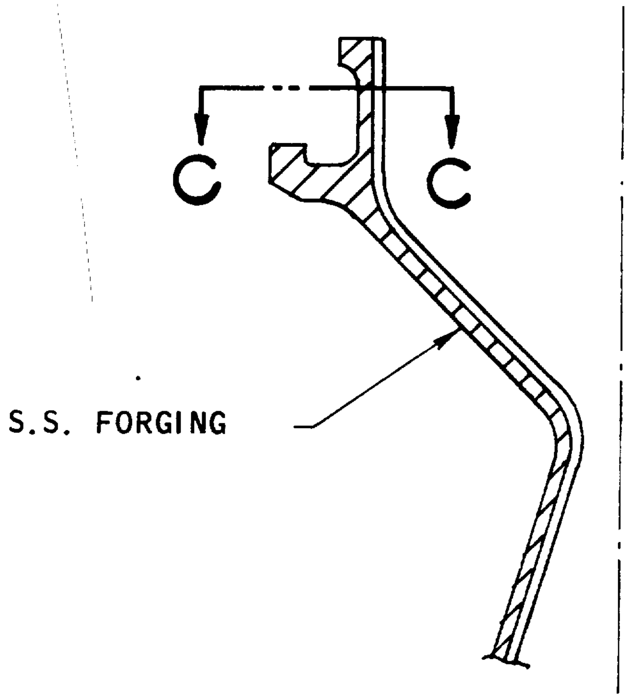


FIGURE A
"U" TUBE NERVA NOZZLE

SECTION C-C

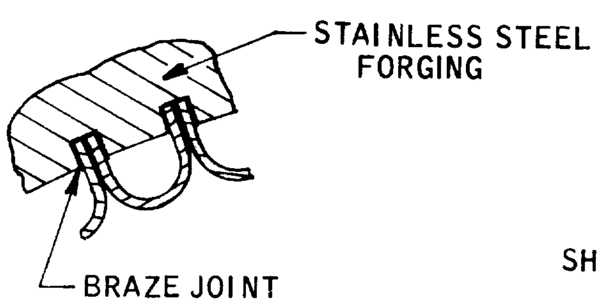


FIGURE B
SHOWING FURNACE BRAZED JOINT
FOR THE "U" TUBE NERVA NOZZLE

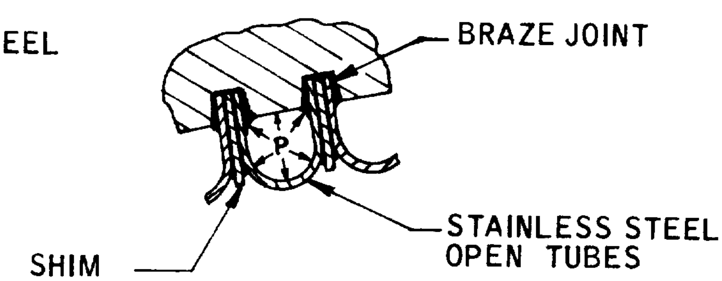


FIGURE C
INTERNAL PRESSURE LOADING ON
"U" TUBE NERVA NOZZLES

Figure 3

"U" Tube NERVA Nozzle Tubes

II. TECHNICAL DISCUSSION

II. TECHNICAL DISCUSSION

A. BRAZE ALLOY EVALUATION AND TEST PROCEDURE

A literature survey and review of past AGC furnace brazing experience confirmed the conclusion that the braze alloys used for conventional thrust chambers would not be acceptable for the U-tube configuration. To be considered for the NERVA U-Tube application and potential braze alloys should meet the following:

1. avoid the interstitial elements (such as boron, silicon, or carbon) that cause enbrittlement of thin walled tubes
2. be producible in wire, foil, and powder form to facilitate alloy placement in the shear joints
3. be insensitive to slight variations in chemical compositions
4. possess narrow liquation ranges and be insensitive to prolonged furnace heating and cooling rates dictated by the mass of the assembly and dissimilar component section size
5. be insensitive to minor furnace atmosphere variations
6. possess acceptable flow characteristics for wide clearances
7. possess adequate mechanical strength and ductility

The braze alloys that meet these requirements are listed in Table I. Nioro (82Au - 18Ni) was selected from the list of alloys as the best candidate because adequate mechanical property data was available (References 3 and 4), the 1850°F brazing temperature was compatible with present fixutring materials and furnace capabilities, and AGC had produced successful assemblies using Nioro braze alloy.

The program to determine assembly and brazing procedures was conducted in the following sequence:

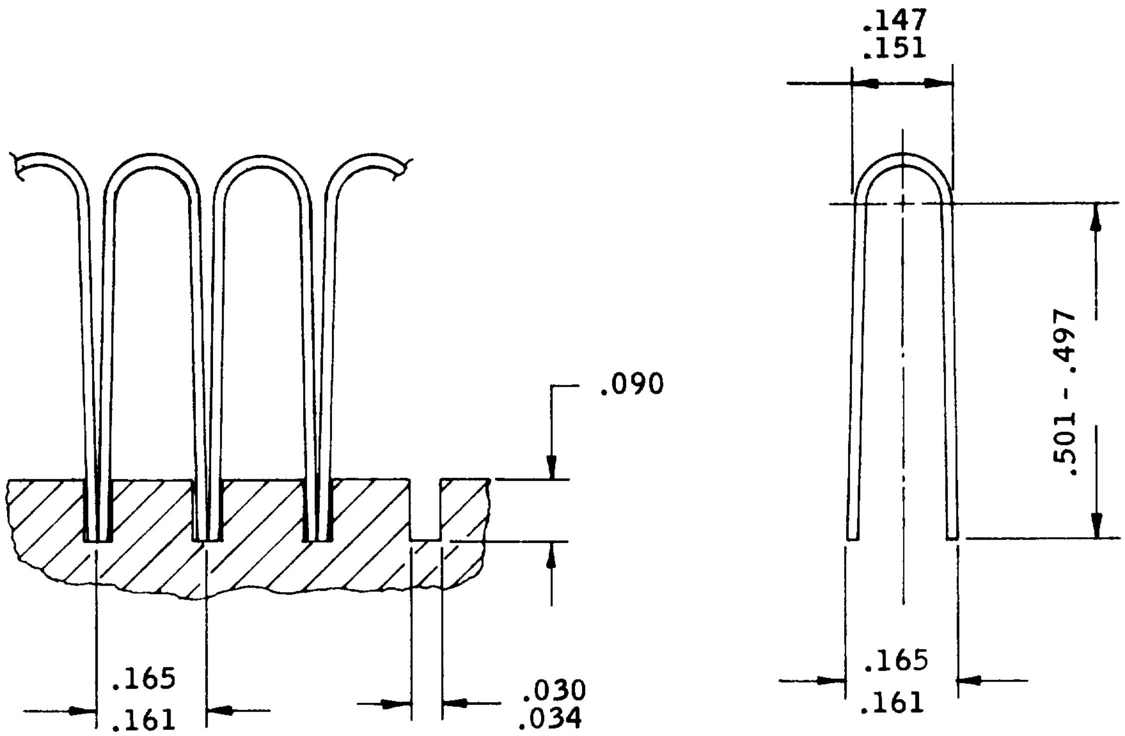
1. Simulated throat specimens

A total of six simulated throat specimens (Figure 4) were assembled and brazed at LRP Materials Research Laboratory using the 10-in. diameter hydrogen furnace. The specimen groove width, braze alloys investigated, and the number

TABLE I

Potential Braze Alloys for NERVA "U" Tube Nozzle Applications

COMMERCIAL TRADE DESIGNATION	CHEMISTRY %				SOLIDUS	LIQUIDUS	BRAZE TEMP
	Au	Ni	Cu	Pd	°F	°F	°F
PALNIRO - 1	50	25		25	2000	2050	2050-2150
PALNIRO - 7	70	22		8	1846	1913	1925-1975
NICORO	35	3	62		1814	1868	1900-1950
NIORO	82	18			1742	1742	1800-1850
NICORO-80	81.5	3	15.5		1652	1670	1700-1750



TUBE WALL = 0.012 $\pm$ .002

NOTE: ALL MATERIAL TYPE 347 STAINLESS STEEL

SPECIMEN "A"

GROOVED PLATES 3" X 8" X 3/4" THICK 15 TUBES FOR EACH PLATE - CENTERED

Figure 4

Simulated Throat Specimens

of furnace braze cycles are listed in Table [illegible]. Braze alloy foil configurations, shown in Figure 5, were hand formed using a two-piece die, then resistance welded to the tube legs. All specimens were sectioned after furnace brazing and subjected to micro-examination. A typical macro section is shown in Figure 6.

The following is a summary of the results obtained for each braze alloy investigated:

a. NIORO (82 Au - 18 Ni)

The 0.0005-in. thick Nioro braze foil used for specimen 1A was produced by Western Gold and Platinum Company, Belmont, California. This foil was preformed to the required configuration, but required extreme care of handling to prevent damage during lay-up and resistance welding to the tube legs. The 0.001-in. thick Nioro foil used to braze specimen [illegible] did not require special handling during assembly. Specimen [illegible] confirmed that the [illegible] braze temperature for 10 minutes for Nioro braze alloy was adequate for the [illegible]-tube joint configuration.

b. Palniro-7 ([illegible] Au - [illegible] Ni - [illegible])

Specimen 1B, using Palniro-7 [illegible]-in. thick foil, produced an acceptable specimen at a braze temperature of [illegible].

c. Nicoro ([illegible] Cu - [illegible] Au - [illegible] Ni)

Specimens 1C and [illegible], using 0.001-inch thick Nicoro braze alloy foil, showed evidence of excessive braze alloy runoff, attributed to the alloy's high copper content.

2. Full Length Production Section Specimens

Full length sections incorporating six grooves, as shown in Figure [illegible], were machined to the contour of NERVA Nozzle S/N-9. Production tubes, formed to the required contour, were used for all specimens. Assembly and furnace brazing was accomplished at Pyromet [illegible], San Carlos, California. Tube-leg faying surfaces were grit-blasted with AMS 4775 (Ni-Cr-Si-B), -150 mesh powder prior to tube lay-up for sections [illegible] through [illegible]. Internal tube crowns were protected during grit blasting with a [illegible] insert. Heat sinks (Figure 8

TABLE II

Simulated Throat Specimen Variation

SPECIMEN NUMBER	GROOVE WIDTH	BRAZE ALLOYS	NUMBER OF CYCLES	
1 A	.0285 .0305	.0015 NIORO FOIL NICORO 80 FOIL & WIRE	4 CYCLES	1850 1740 1780 1740
2 A	.0310 .0320	.001 NIORO FOIL	2 CYCLES	1850 1870
1 C	.0315 .0320	.001 NICORO	2 CYCLES	1910 1910
1 B	.0320 .0325	.001 AGC-7 FOIL	2 CYCLES	1970 1970
2 C	.0325	.001 NICORO FOIL	2 CYCLES	1910 1910
4 A	8 GROOVES .0330 .0335 8 GROOVES .0385 .0390	.001 NIORO FOIL	2 CYCLES	1850 1850

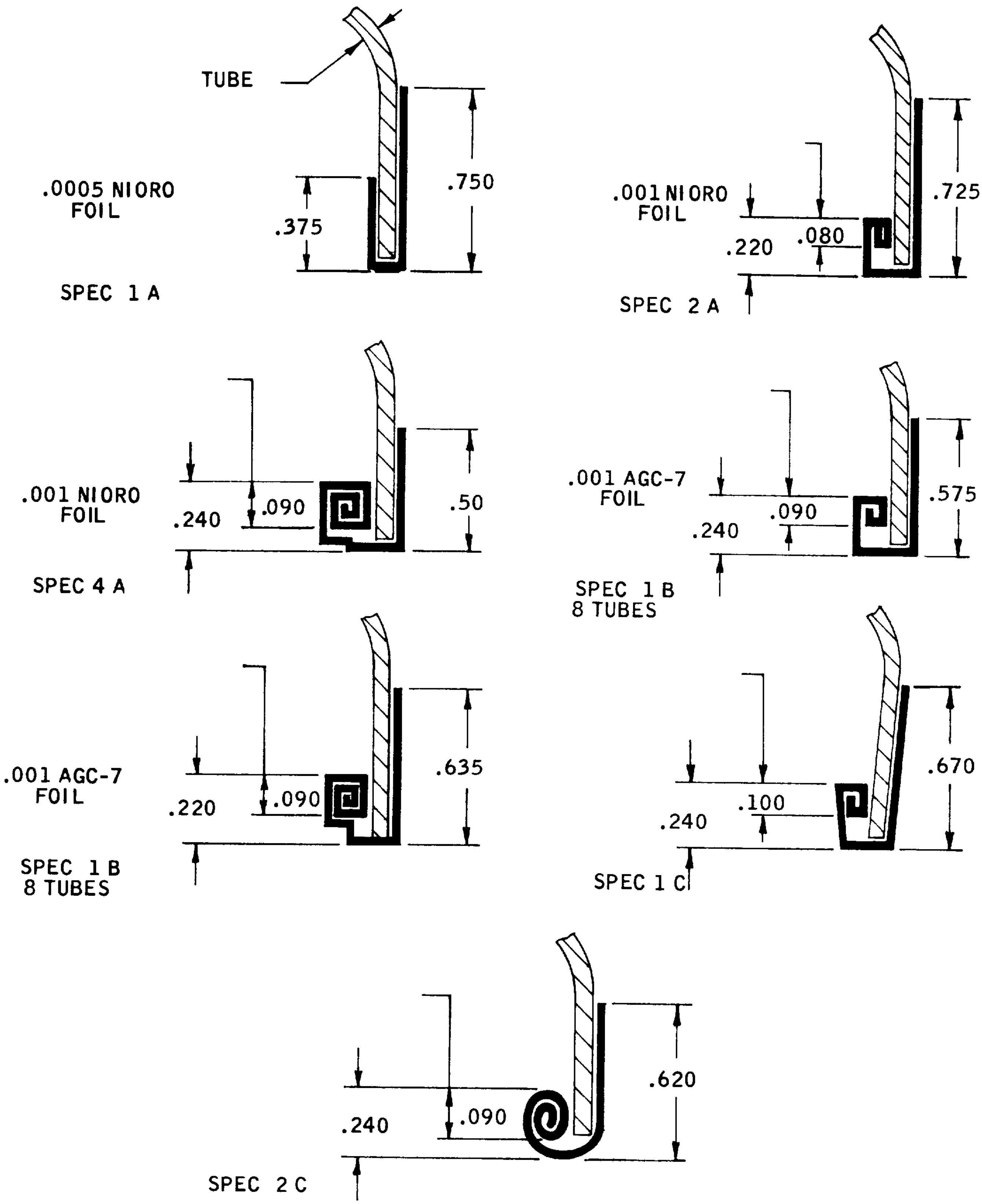


Figure 5

Braze Alloy Foil Configurations for Simulated Throat Specimens

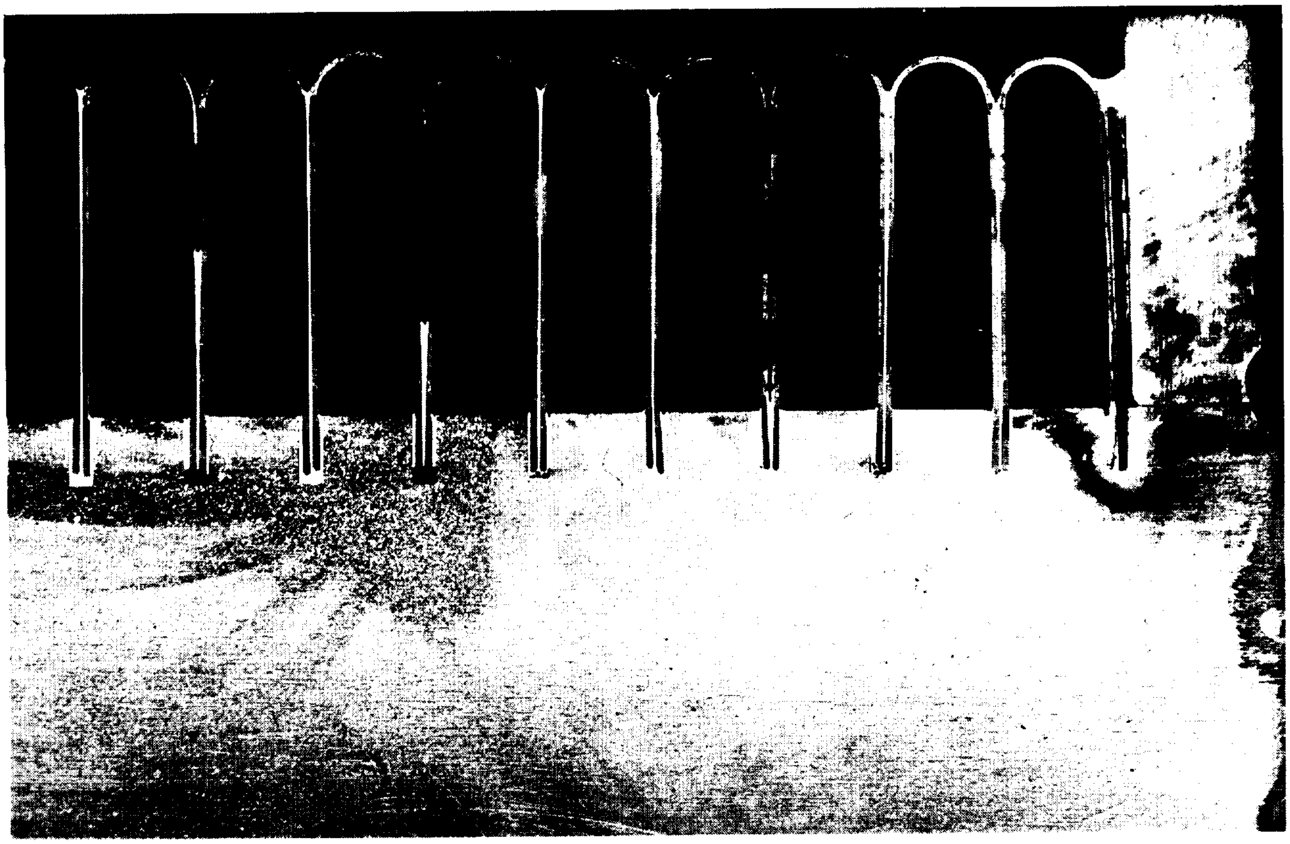


Figure 6

Macro Section of a Typical Simulated Throat
Specimen showing Braze Joint Coverage

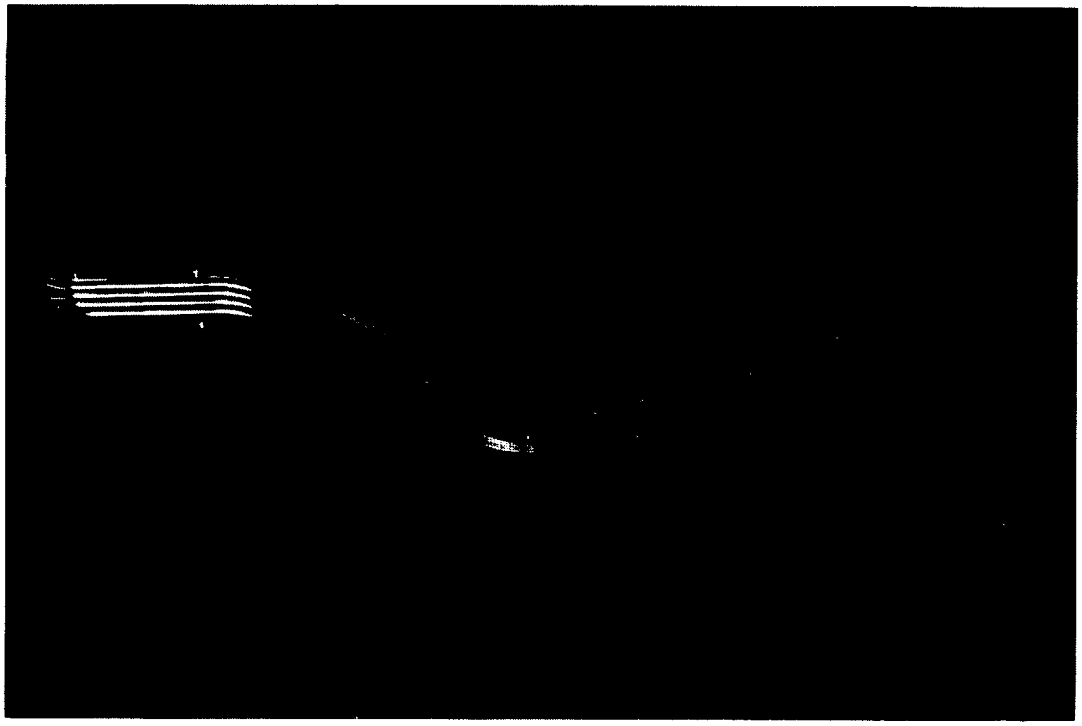
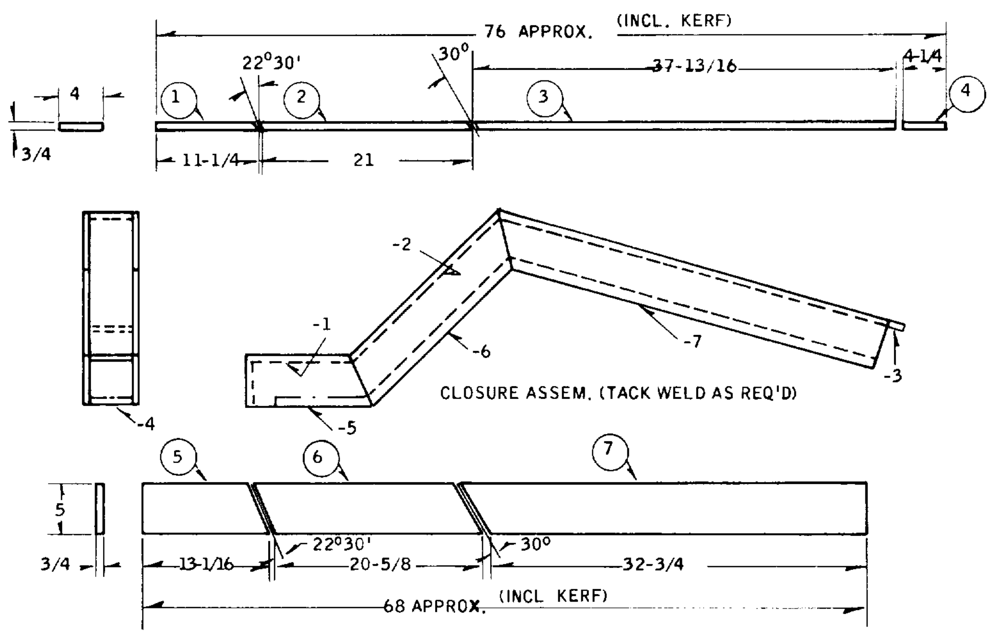


Figure 7

Full Length Section Incorporating Six Full Length NERVA "U" Tubes



BILL OF MATERIAL

NO. REQ'D	MATERIAL & SIZE
1	CRES 347 3/4 x 4 x 76 MAKES (1) EA. DETS. -1, -2, -3 & -4
2	CRES 347 3/4 x 5 x 68 MAKES (2) EA. DETS. -5, -6 & -7

Figure 8

Sector Heat Sink Configuration

fabricated from 3/4-in. type 347 stainless steel were attached to the sector faces during the braze cycles to duplicate metal temperatures of the actual part. Five thermocouples were attached to the sectors at the places indicated in Figure 9, and actual metal temperatures were continuously recorded during the braze cycles (Figure 10). Heating and cooling rates were controlled, except for Sector 5, to simulate actual hardware furnace conditions. All sections, except Sector Number 1, were hydro-tested to leak, proof, and burst pressures as specified in Appendix A. After hydro-tests the sectors were visually examined, sectioned and subjected to metallographic examination. Macro-sections taken from Sector 6, which are typical for all sectors, are shown in Figure 11 through 13.

Groove dimensions, braze alloy placement, braze temperatures, and hydro test results are presented in Figure 14 through 20. The significant factors observed during assembly, and a discussion of the test results obtained for each sector, are as follows:

a. Sector 1:

(1) Procedure

The tubes and simulated jackets used for this sector were reworked from scrapped components which did not meet blueprint dimensional requirements, but which provided desired assembly and processing data. Actual groove dimensions were as shown in Table III. The groove widths were within drawing tolerances but the groove depths exceeded the maximum drawing dimension by 0.012-in. The sector was removed from the machining ring fixture (Figure 21) by flame cutting with an oxy-acetylene torch. The heat generated during this operation distorted the cylindrical section of the sector which had to be heated, shimmed, and straightened prior to assembly. The tubes did not fit the contour of the sector and had to be scribed and hand filed in the throat to approximate the contour of the grooved sector. Assembly was attempted at AGC-LRP Sacramento. The tube throat widths were excessive at the point of tangencies, which prevented assembly beyond the second tube. The braze alloy foils attached to the tube legs were torn when the tube legs were forced into the grooves. Assembly of this sector was discontinued.

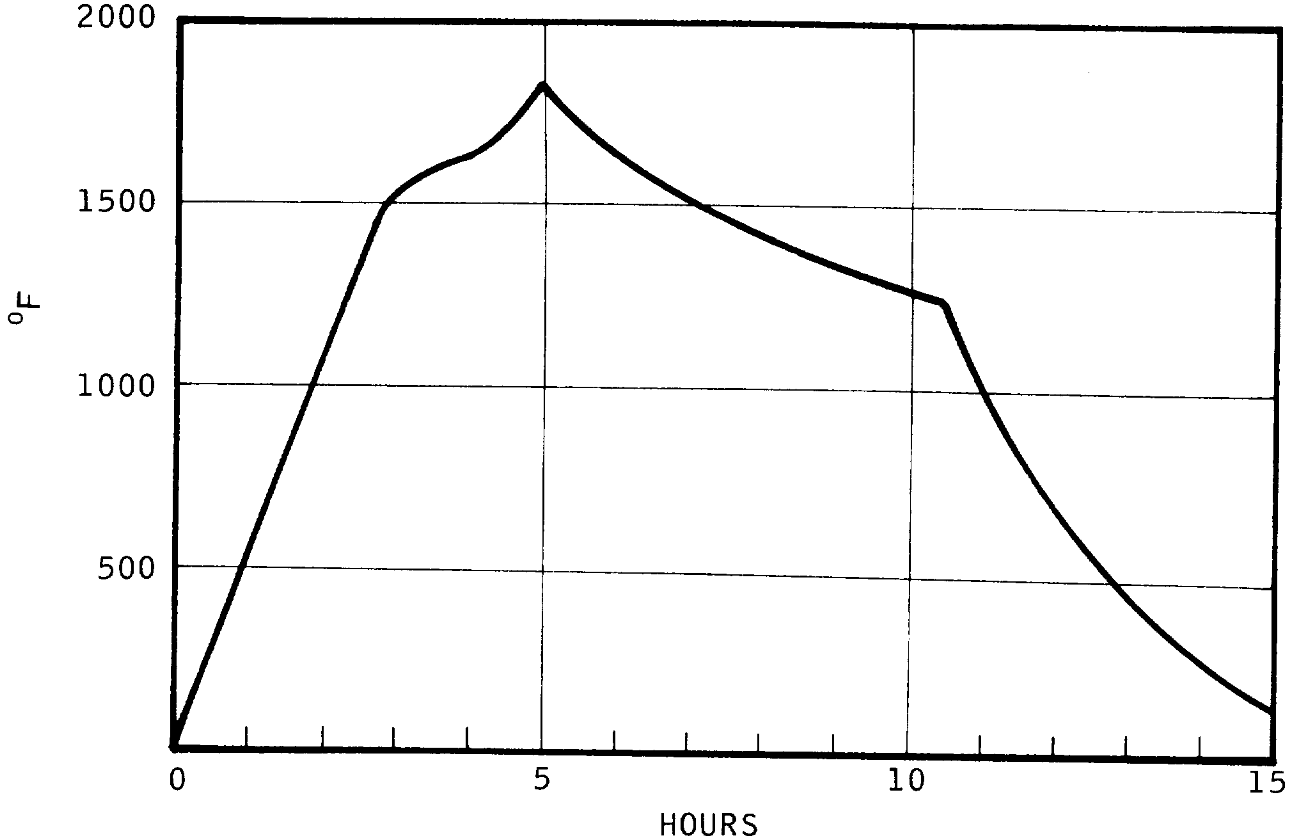


Figure 9

Thermocouple Locations

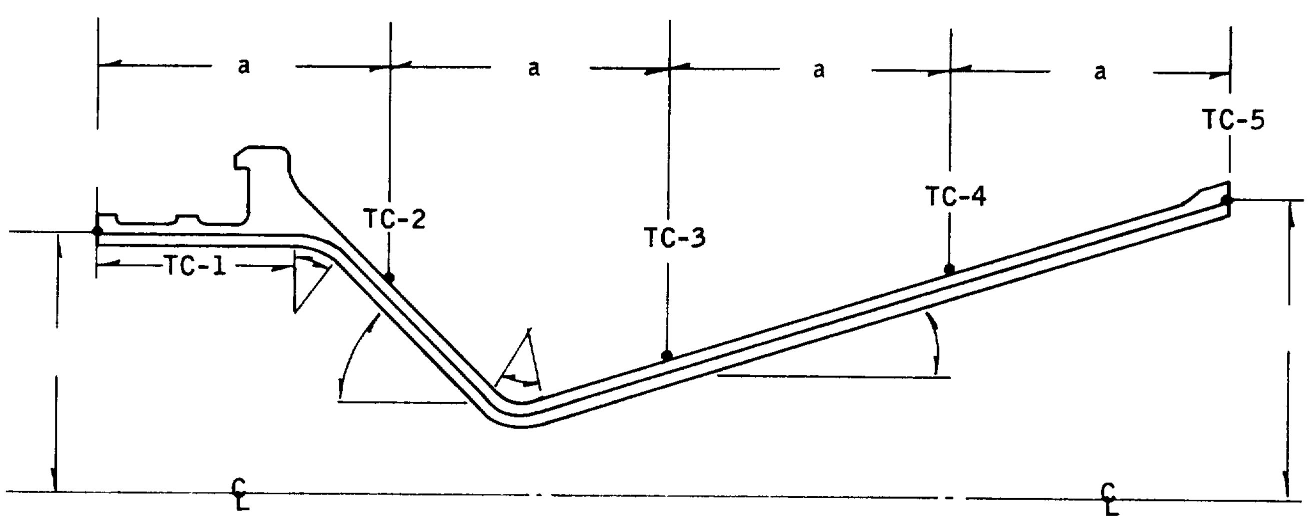


Figure 10

Typical Time - Temperature Braze Cycle for Sector Fabrication

TABLE III

Groove Dimensional Inspection Results for Sector 1

STATIONS	GROOVE 1		GROOVE 2		GROOVE 3		GROOVE 4		GROOVE 5		GROOVE 6	
	W	D	W	D	W	D	W	D	W	D	W	D
A	37	97	37	96	37	98	37	97	37	96	37	97
B	37		37		37		36		36		36	
C	38	97	38	96	38	96	38	98	38	97	38	95
D	36	96	36	96	36	96	36		36		36	
E	38		38		38		38		38		38	
F	38	112	38	112	38	109	38	108	38	108	38	108
G	39	108	39	108	39	104	39	105	39	105	39	104
H	39	106	39	106	39	103	39	102	39	102	39	102
I	39	106	39	105	39	102	39	102	39	102	39	102
J	39	104	39	104	39	101	39	100	39	100	39	100

REQUIRED WIDTH = .036 - .039
REQUIRED DEPTH = .090 - .100

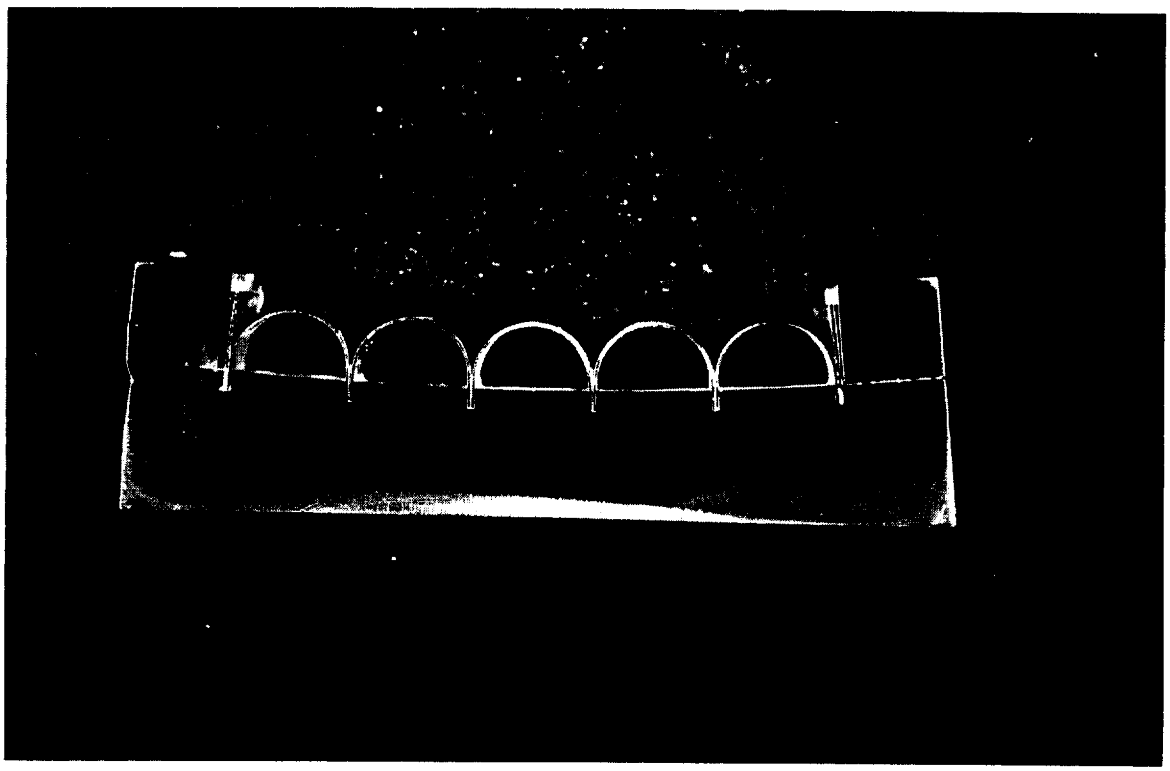


Figure 11

Typical Macro Section taken from the Cylindrical Section

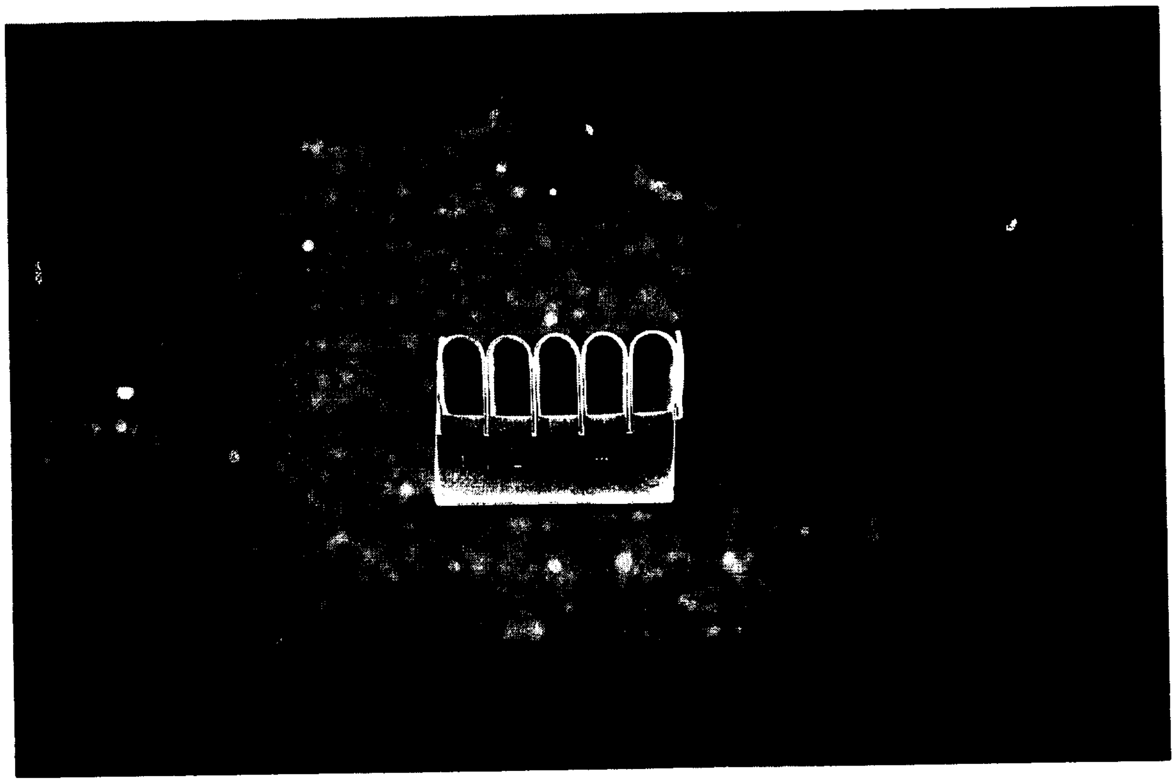


Figure 12

Typical Macro Section taken from the Throat Area

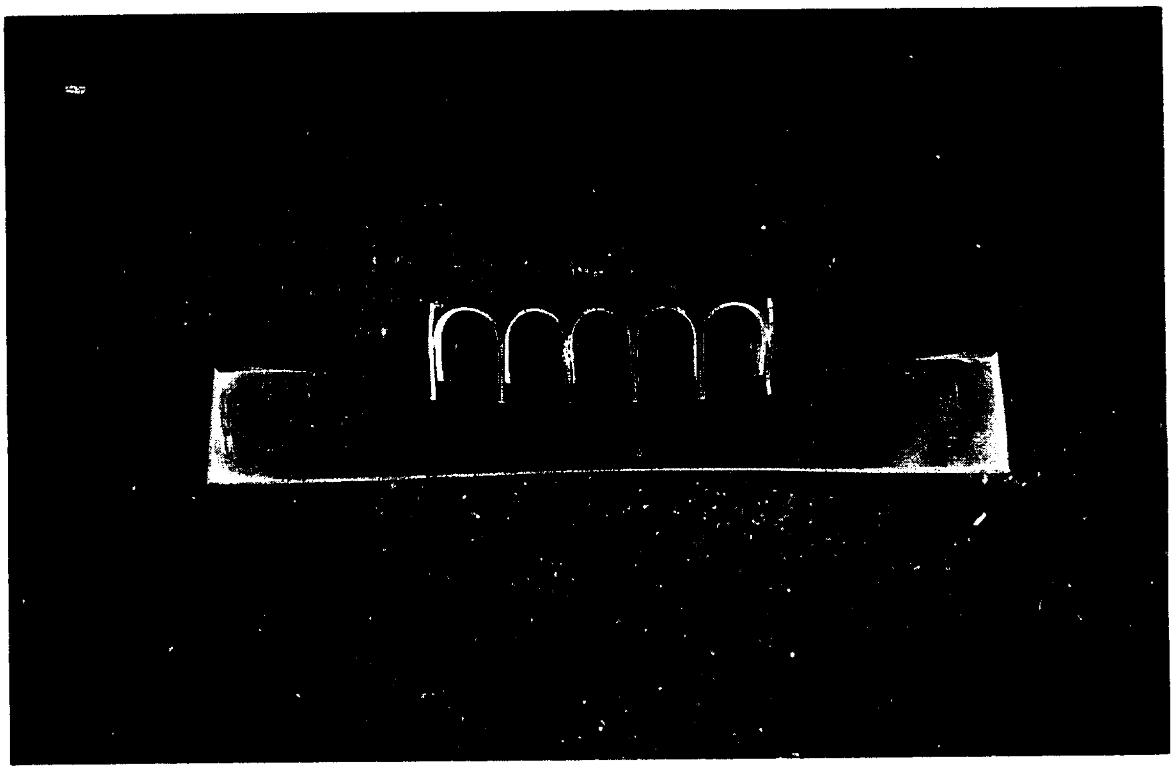


Figure 13

Typical Macro Section taken from the Aft Area

FOLDOUT FRAME 2

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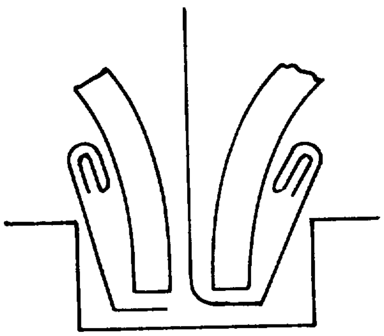


SECTOR 1 VARIABLES

FOIL = 0.001 INCH THICK NIORO

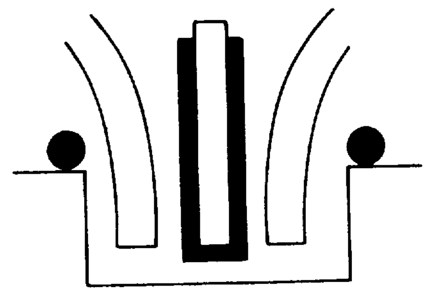
GROOVE WIDTH = 0.036 - 0.039 INCH

BRAZE TEMP = NOT ACCOMPLISHED

HYDRO BURST PRESSURE = NOT ACCOMPLISHED

Figure 14

Braze Alloy Configuration For Sector 2



SECTOR 2 VARIABLES

WIRE = 0.020 INCH DIAMETER NIORO

FOIL = 0.001 INCH THICK NIORO

GROOVE WIDTH = 0.036 - 0.039 INCH

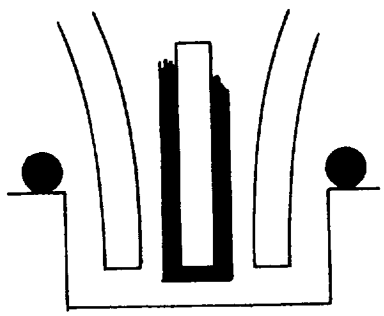
SHIM THICKNESS = 0.004 - 0.005 - 0

BRAZE TEMP = 1825 - 1850^{0} F

HYDRO BURST PRESSURE = 1080 PSI

Figure 15

Braze Alloy Configuration For Sector 2



SECTOR 3 VARIABLES

FOIL = 0.001 INCH THICK NIORO

WIRE = 0.020 INCH DIAMETER NIORO

GROOVE WIDTH = 0.037 - 0.038 INCH

SHIM THICKNESS = 0.006 INCH

06 INCH

1ST BRAZE TEMP = 1825 - 1850° F

2ND BRAZE TEMP = 1850 - 1875° F (NO ADDITIONAL BRAZE ALLOY ADDED)

HYDRO BURST PRESSURE - 3250 PSI

Figure 16

Braze Alloy Configuration For Sector 3

FOLDOUT FRAME 2

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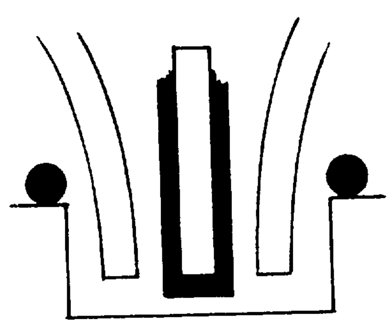


SECTOR 4 VARIABLES

WIRE = 0.020 INCH DIAMETER NIORO

FOIL = 0.001 INCH THICK NIORO

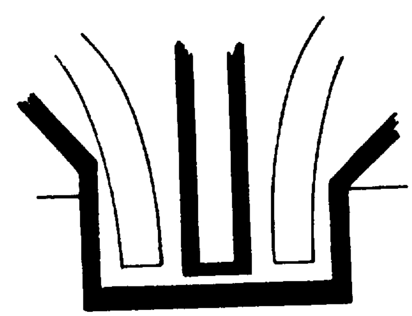
GROOVE WIDTH = 0.036 - 0.039 INCH

BRAZE TEMP = 1825 - 1850° F

HYDRO BURST PRESSURE = NOT REPORTED

Figure 17

Braze Alloy Configuration For Sector 4



GROOVES 1, 2, & 3

AGC

SECTOR 5 VARIABLES

FOIL = 0.001 INCH THICK N

WIRE FOR GROOVES 4, 5, A
DIAMETER NIORO

GROOVE WIDTH = 0.051 - 0

SHIM THICKNESS = 0.012 I

1ST BRAZE TEMP = 1825 -

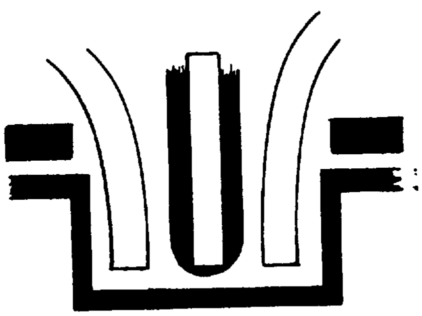
2ND BRAZE TEMP = 1850 -

3RD BRAZE TEMP = 1800 -

HYDRO BURST PRESSURE =

Figure 18

Braze Alloy Configuratio



GROOVES 4, 5, & 6

ORNL - AGC

ORO

ND 6 = FLATTENED 0.014 INCH

052 INCH

ICH

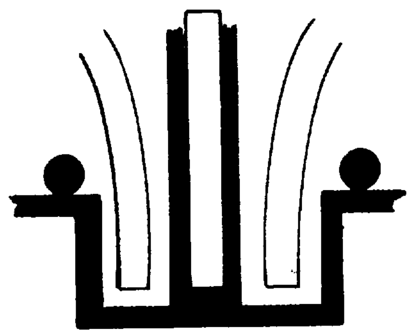
1850° F

1875° F (NO ADDITIONAL BRAZE ALLOY ADDED)

1825° F (PALNIRO -7 AND NIORO POWDER ADDED)

4100 PSI

n For Sector 5



AGC

SECTOR 6 VARIABLES

FOIL = 0.001 INCH THICK NIORO

WIRE = 0.020 INCH DIAMETER NIORO

GROOVE WIDTH = 0.037 - 0.039 INCH

SHIM WIDTH = 0.005 INCH

1ST BRAZE CYCLE = 1825 - 1850° F

2ND BRAZE CYCLE = 1800 - 1825° F

(PALNIRO -7 AND NIORO POWDER ADDED)

3RD BRAZE CYCLE = 1750 - 1775° F

(NICORO -80 POWDER ADDED)

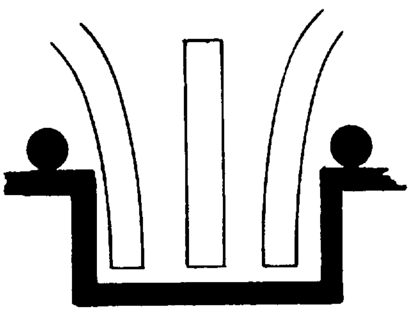
HYDRO BURST PRESSURE = 4175 PSI

Figure 19

Braze Alloy Configuration For Sector 6

FOLDOUT FRAME 2

19-2



ORNL

SECTOR 7 VARIABLES

FOIL = 0.001 INCH THICK NIORO

WIRE = 0.020 INCH DIAMETER NIORO

GROOVE WIDTH = 0.037 - 0.039 INCH

SHIM WIDTH = 0.007 INCH

1ST BRAZE CYCLE = 1825 - 1850°F

2ND BRAZE CYCLE = 1800 - 1825°F (PALNIRO -7 AND NIORO POWDER ADDED)

3RD BRAZE CYCLE = 1750 - 1775°F (NICORO -80 POWDER ADDED)

HYDRO BURST PRESSURE = 4050 PSI

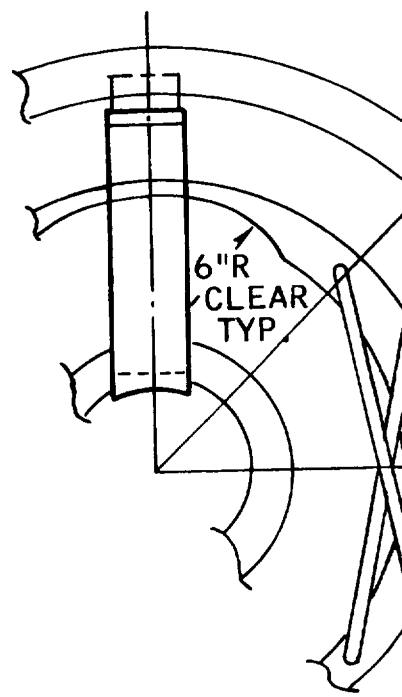


Figure 20

Braze Alloy Configuration For Sector 7

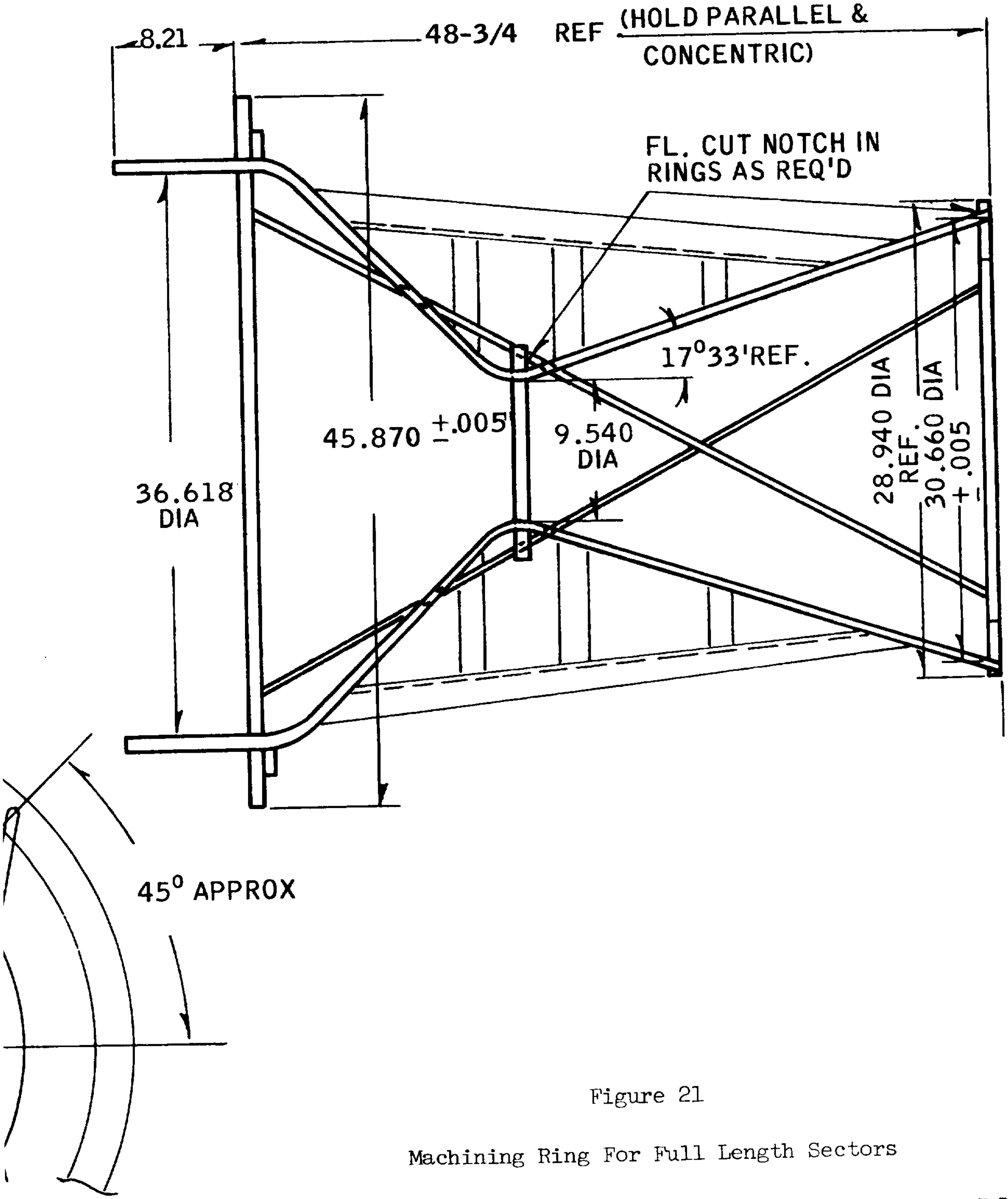


Figure 21

Machining Ring For Full Length Sectors

FOLDOUT FRAME 2

~~CONFIDENTIAL~~

(2) Corrective Action

(a) The tube vendor (Marquardt Corp., Ogden, Utah) was instructed through AGC Projects and Purchasing to reduce the tube width at the throat prior to forming tubes for NERVA Nozzle S/N-9.

(b) Attachment of the foils directly to the tube legs prior to assembly was discontinued on future sectors and nozzles.

(c) Project was advised that sectors must be removed from the machining ring by milling instead of flame cutting to avoid distortion.

b. Sector 2:

(1) Procedure

Removing the foils from the tube legs (the alloy placement technique for sector number one) left an additional 0.003-in. clearance between the tube and groove walls. Sector 2 incorporated a shim between the tubes which locked out the clearances required for assembly.

The groove dimensions for Sector 2 (Table IV) were approximately the same as for Sector 1. Tube wall thickness (Table V) exceeded the maximum drawing dimensions of 0.016 in. by 0.001 in. Both the tubes and the sector were reworked in the same manner as described for Sector 1. The components were shipped to Pyromet Inc., San Carlos, for assembly and brazing. Type 302 stainless steel cold-rolled shim stock, sheared to the tapered widths shown in Figure 22, was positioned between the tubes. The fixture and grooved specimen were shortened by eight inches to fit a retort 52 in. long. The tubes were cut to fit the grooved specimen length.

Alignment of the 0.020-in.-diameter Nioro wire to the sides of the jacket grooves was accomplished by placing an insulated 0.030-in. thick stainless steel shim in the groove and forcing the wire against the shim. The wire was resistance-welded to the jacket at half-inch intervals using a 200-watt-second maximum capacity Stryco welder. Effective machine settings were 40- to 50-watt-seconds. Approximate wire lay-up time was 15 min.-per-groove.

Original plans called for resistance welding of the tube legs to the groove walls in relieved areas; however, tube fit-up in the cylindrical section was

TABLE IV

Groove Dimensional Inspection Results for Sector 2

STATIONS	GROOVE 1		GROOVE 2		GROOVE 3		GROOVE 4		GROOVE 5		GROOVE 6	
	W	D	W	D	W	D	W	D	W	D	W	D
A	38	105	38	104	38	104	38	105	38	106	38	105
B	38		38		38		38		38		38	
C	38	101	38	100	38	101	38	101	38	101	38	100
D	37	102	37	102	37	100	37	101	37	101	37	102
E	38		38		38		38		38		38	
F	37	112	37	112	37	112	37	111	37	111	37	110
G	37	109	37	109	37	109	37	109	37	109	37	110
H	38	107	38	108	38	107	38	108	38	108	38	108
I	38	106	38	106	38	106	38	106	38	106	38	106
J	38	105	38	105	38	106	38	105	38	106	38	105

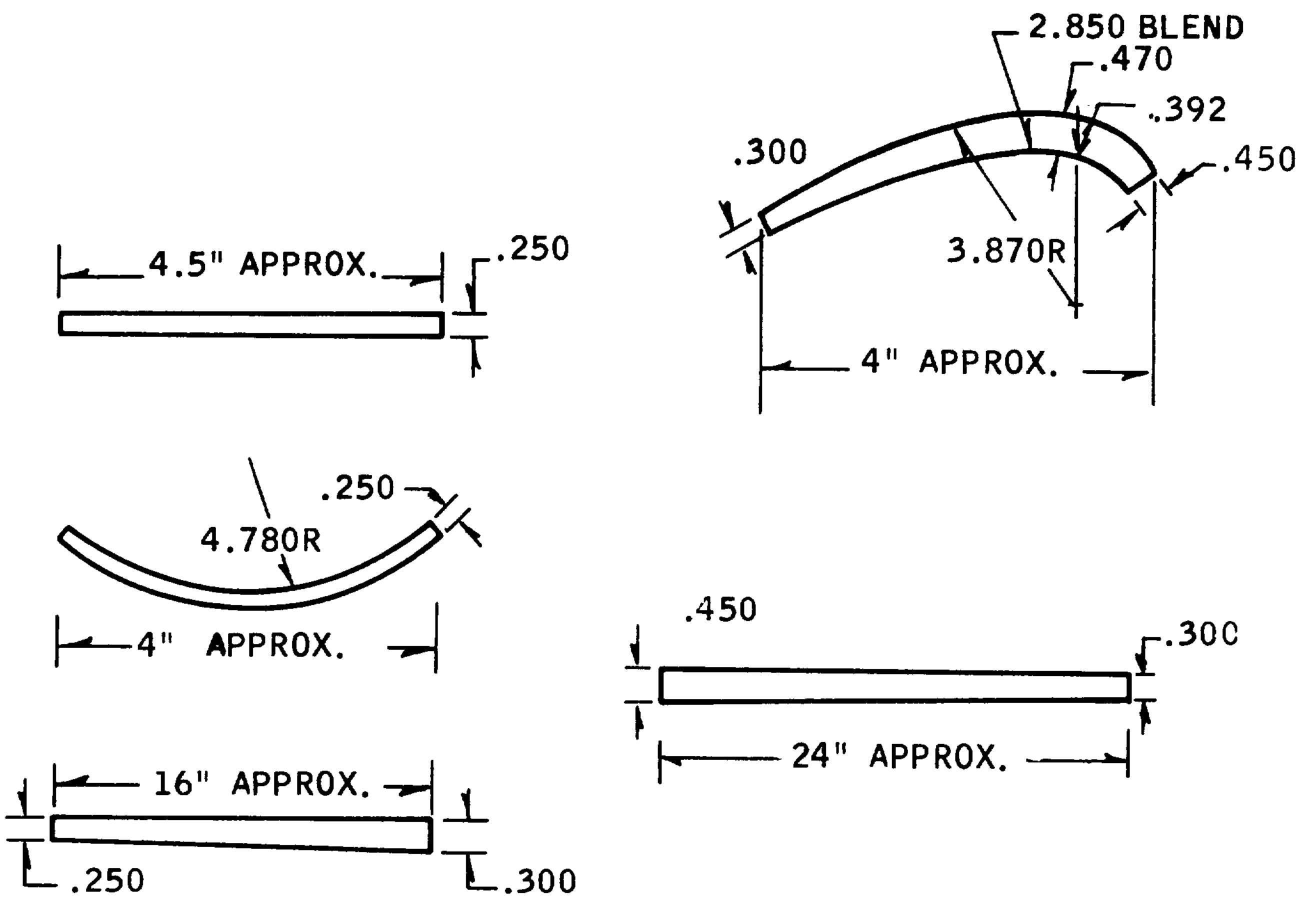
TABLE V

Tube Wall Thickness for Sector 2 in Inches

	DIMN	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	STATION 6	STATION 7	STATION 8	STATION 9	STATION 10
S/N 1	T_1	.0157	.0138	.014	.0135	.013	.013	.014	.0138	.014	.014
	T_2	.0165	.0143	.0138	.0135	.0132	.0135	.016	.014	.0138	.0138
	T_c	.014	.0148	.0148	.0148	.0147	.0146	.0144	.0145	.0146	.0143
S/N 2	T_1	.0168	.0162	.017	.0146	.0148	.0145	.0146	.0148	.015	.014
	T_2	.0166	.0155	.0173	.0139	.0148	.0142	.014	.0143	.0143	.0129
	T_c	.0146	.0148	.0153	.0147	.0145	.0147	.0148	.0146	.0145	.0143
S/N 3	T_1	.0152	.0165	.016	.0138	.0152	.0135	.014	.0138	.014	.0138
	T_2	.017	.0155	.0165	.0148	.014	.0142	.0153	.0138	.014	.013
	T_c	.0163	.0165	.0166	.0161	.0160	.0166	.0166	.0165	.0167	.0165

T_1 = RIGHT LEG, T_2 = LEFT LEG, T_c = CROWN

DRAWING REQUIREMENT = 0.012 TO 0.0160 IN



MATERIAL

TYPE 347 STAINLESS STEEL SHIM STOCK

not acceptable, as a result of improper tube contour. Slight kinks, twists, bulges and burrs on the tube legs made tube lay-up difficult. When tube legs were restrained by resistance welding at the relieved areas, the tubes bulged out of the grooves between the welds when shimmed. Resistance welding of the specimen tube legs to the groove walls was discontinued for this Sector.

Nioro foil, 0.001-in. thick, was resistance welded to the stainless steel shims, cut in four-inch length, and forced between the tubes. Shims were placed between all four tubes in the cylindrical section, then at the convergent section by starting at the pressure vessel flange and progressing to the core support flange. Shims were then placed progressively from the pressure vessel flange to the propellant inlet end of the nozzle.

The shims were driven to the bottom of the grooves by placing 0.010-in. Starrer stock over the shims. This method for placement of shims was not acceptable, as the stock slipped off the shim and was locked between the tube wall and the side of the shim. The specimen was brazed at Pyromet Inc., and shipped to AGC for Hydro test.

The 500-psi leak check indicated gross leakage and the sector was repaired using an oxy-acetylene torch, Easy Flow 45 alloy, and Handy and Harmon high temperature flux. No adverse difficulties were encountered during localized leak repair.

The sector was returned to the hydro lab for proof test. Failure of the braze shear joint occurred accompanied by tube pullout between the convergent and cylindrical section at 1080 psi, 70 psi below the 1150 psi proof pressure.

(2) Corrective Action

(a) The tube vendor (Marquardt Corp., Ogden, Utah) was informed through AGC Projects and Purchasing that the tube wall thicknesses were not within the drawing requirements.

(b) Shim driving blanks were designed by Materials Research personnel for assembly of the next sector.

(c) It was recommended that additional sectors be made prior to fabrication of NERVA Nozzle S/N-9.

c. Sector 3:

(1) Procedure

This sector was assembled using 0.006-in. shims and shim-driving blanks described in the tooling section of this report. Braze alloy placement was the same as for sector number one. The full length sector was brazed in the Pyromet production furnace and was improperly manifolded during the first braze cycle. An inadequate flow of the protective hydrogen atmosphere oxidized the internal tube walls. The sector was inverted and recycled at a 25°F higher braze temperature, with approximately 250 cubic-feet-per-hour hydrogen flow diverted to the internal tube walls. The increased hydrogen flow at higher temperatures reduced the oxides and reflowed the excess braze alloy. The nozzle was subjected to leak check. The leaks were repaired using the Easy Flow 45 alloy and techniques established for sector number two. After localized repair, the sector passed the 1150-psi proof pressure and burst at 3250 psi. Visual examination after failure revealed the tubes pulled out of the grooves in the aft section. Metallographic examination of the failed section showed evidence of minimum braze alloy coverage in the shear joints, and lack of bottoming of the shim in the failed area (Figure 23). The tight shim caused a zero clearance in the shear areas and prevented braze alloy flow.

(2) Corrective Action

(a) The shim width for Sector 4 and NERVA Nozzle S/N-9 was reduced to .005 in. to provide adequate clearance between the tube legs and groove walls.

(b) On subsequent sectors and nozzles, the protective hydrogen manifolding was cold-purged prior to sealing the retort to guarantee an adequate flow of hydrogen to prevent oxidation of internal tube walls.

(c) Project was requested to supply sectors with increased groove widths to allow placement of braze alloy foil in the shear joints. This foil will prevent zero clearance and insure adequate braze alloy coverage in the shear areas. The increased groove widths could not be scheduled for NERVA Nozzle S/N-9 because the grooving operation was almost complete.

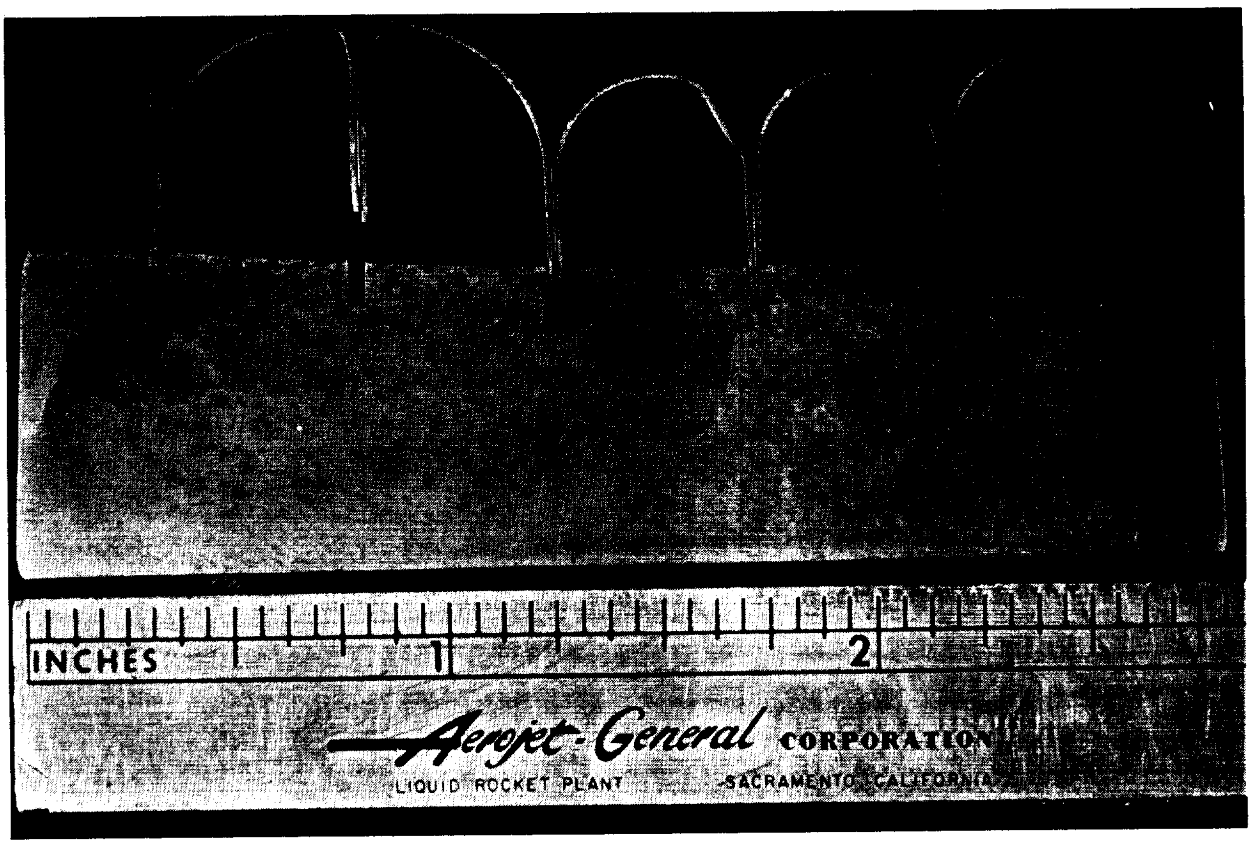


Figure 23

Failed Joint in Sector 3

d. Sector 4:

(1) Procedure

This sector was assembled and brazed at Pyromet parallel with NERVA Nozzle S/N-9. The groove width, shim thickness, and alloy placement was the same as for NERVA Nozzle S/N-9. Spacers for locating the braze wire adjacent to the groove edge were pressed from glass reinforced phenolic resin and cut to the contour of the nozzle. These spacers were placed in the grooves and the braze alloy wire was positioned next to the spacer for resistance welding. Shim driving blanks fabricated for NERVA Nozzle S/N-9 were used to assemble this sector. Assembly was considerably easier and faster than for past sectors.

The sector was subjected to leak check, locally repaired using Easy Flow 45, and then proof pressure checked. After proof test the sector was burst at an unreported pressure. Mode of failure was tube pull-out from the groove in the cylindrical section. The specimen was sectioned and sent to the weld shop to be used for the development of a leak repair procedure for NERVA Nozzle S/N-9. Metallographic examination was not accomplished for this specimen.

(2) Corrective Action

(a) The problems encountered during the localized torch repair of NERVA Nozzle S/N-9 required additional work on the sectors to develop furnace brazing cycles in order to prevent leaks.

(b) Additional sectors with wider grooves were scheduled to facilitate braze alloy foil loading in the shear joints. These foils will insure braze alloy flow in the shear joints to prevent tube pull-out from the grooves.

e. Sector 5:

(1) Procedure

This sector was assembled using a .051-in. to .052-in. wide groove. Two types of braze-loading configurations, using foils preplaced in the grooves, were used. Hand forming the foils to the contour of the sector and to the exact groove dimensions was tedious and ineffective. The dielectric foil spacers did not position the foil properly in the groove. The square edges of the flattened wire made tube lay-up difficult. During assembly the 0.012-in.-wide shims did not fit tightly between the tubes. Gaps between the shim ends were noted after the first cycle, probably caused by the application of a fast heating rate.

Additional alloy was not applied prior to the second cycle and the specimen was inverted and recycled to seal the forward flange. After the second cycle the specimen was subjected to hydro leak check (Figure 24). The Palniro-7 braze alloy powder was then applied to the shim ends and Nioro powder braze alloy was overlayed on the Palniro fillet, as described in the Development of the Third Cycle section of this report. The third brace cycle was accomplished at 1800-1825°F. Leak checks after the third cycle revealed one leak, which was torch repaired using BT alloy.

Sector 5 was proof tested at 1150 psi and burst at 4100 psi. Visual examination after hydro tests revealed that failure occurred in the tube crown at the cylindrical section. Metallographic examination revealed an average of 25% void areas in the shear joints. In all cases one of the two side wall joints for each groove had 100% coverage, and that was the joint with minimum clearance. Both types of alloy placement techniques investigated had less cross sectional area of braze alloy coverage than observed for previous sectors.

(2) Corrective Action

(a) The wide shim approach was abandoned because the present tube width at the throat does not permit the use of wide shims. No plans are forthcoming for a narrow tube.

(b) Annodized aluminum foil positioning spacers were designed for use with round braze alloy wires. Annodized aluminum spacers were used successfully by Marquardt for the assembly of NERVA Nozzle S/N-8.

(c) All future brazing cycles for sectors and nozzles will require a controlled rate of heating and cooling.

(d) A contract was released to Western Gold and Platinum, Belmont, California, to produce a foil folding machine to eliminate the problems encountered with hand folded foils.

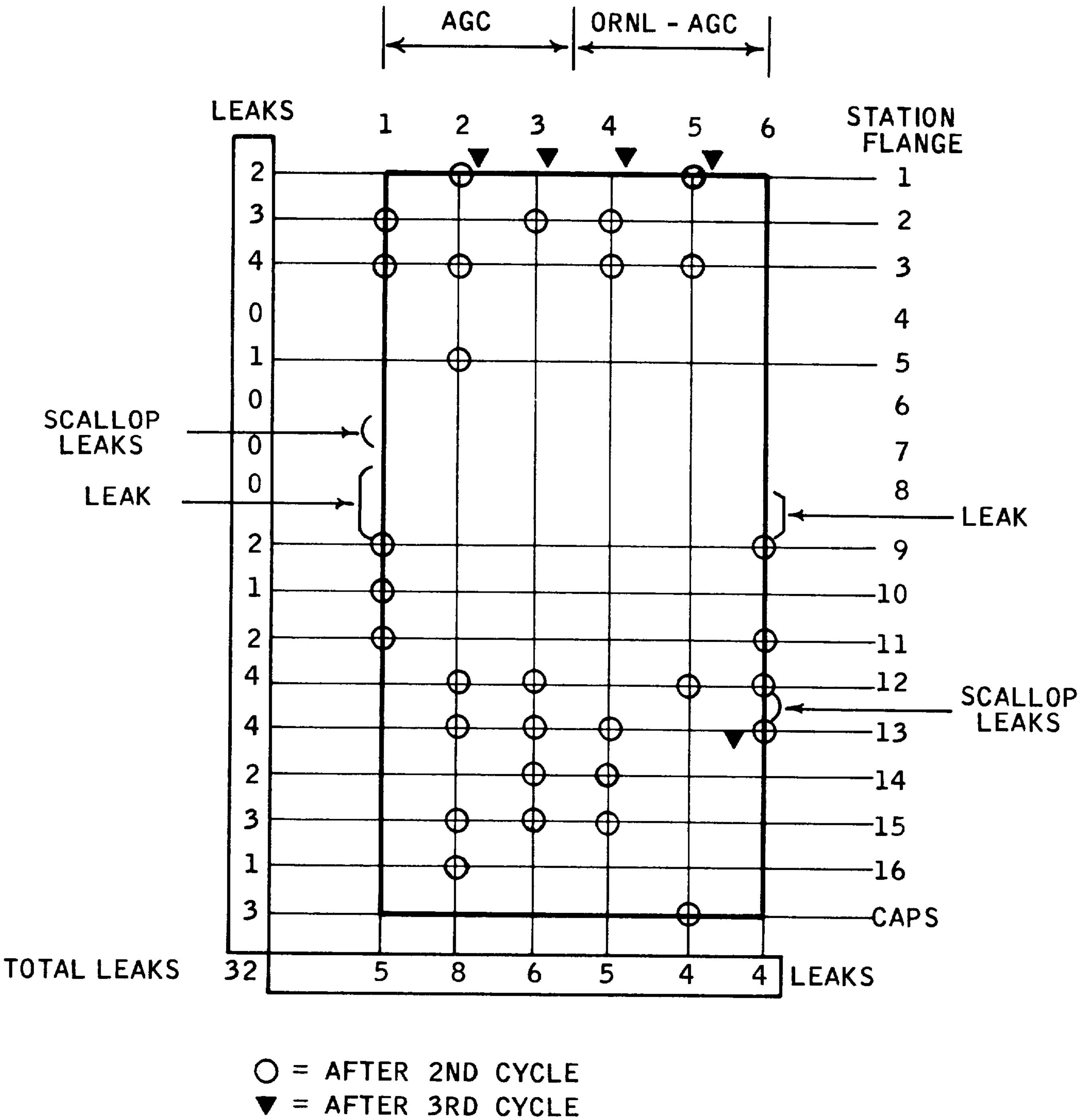


Figure 24

Location of Leaks for Sector 5

(e) Future sectors and nozzles require the use of the Palniro-7 fillets overlayed with Nioro at the shim ends.

f. Sectors 6 and 7:

(1) Procedure

Sector 6 was machined and assembled to duplicate the procedure scheduled NERVA Nozzle S/N-22. Sector 7 was loaded without the braze alloy foil around the shim. The sectors were shipped to Pyromet in the machining ring. This ring had been annealed in air and the scale removed by air blasting with garnet grit. The sector grooves were loaded with hand folded foils using annodized aluminum positioning spacers.

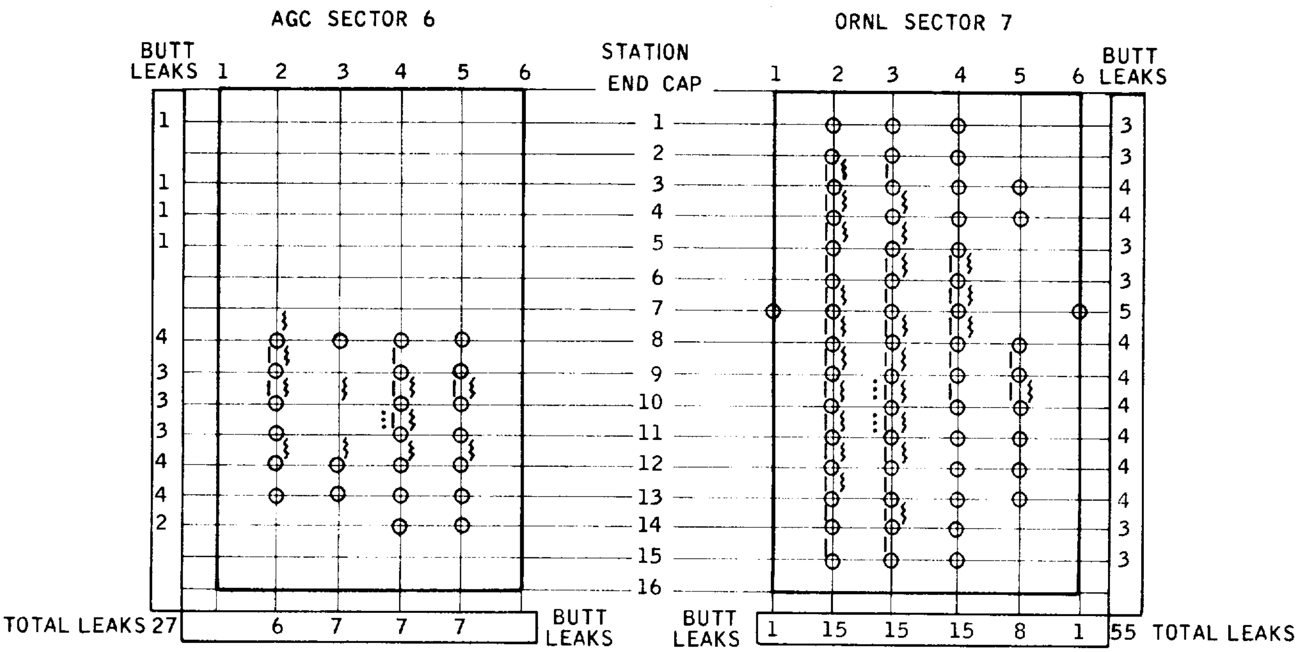
Tubes were loaded, and both sectors brazed at 1825-1850°F. After the first cycle, both specimens and the machining ring were heavily oxidized. The oxide had reduced from the machining ring and transferred to the components being brazed. Both sectors were milled from the machining ring and subjected to low pressure leak check and leak locations recorded (Figure 25). The sectors were recycled, using the Palniro-7 Nioro overlays at the shim ends, and the leaks again recorded. Both sectors were then loaded with Nicoro-80 powder on the fire wall tube-to-tube joints and recycled at 1750-1775°F. The remaining leaks were torch-repaired with BT alloy and hydro tested.

Sector 6 failed at a burst pressure of 4175 psi and Sector 7 at 4050 psi, with both failures occurring in the tube crowns at the cylindrical section.

(2) Corrective Action

(a) Future fixtures and components shall be annealed in a dry hydrogen atmosphere to prevent contamination during the brazing cycle.

(b) Three furnace brazing cycles were scheduled for future NERVA Nozzles to prevent potential leak paths.



O = SHIM BUTT END LEAK
| = 1ST BRAZE CYCLE - NIORO ALLOY, 1825°-1850°F FOR 5-10 MIN.
§ = 2ND BRAZE CYCLE - NIORO ALLOY & AGC 44079, 1800°-1825°F FOR 5-10 MIN.
⁝ = 3RD BRAZE CYCLE - NIORO ALLOY, 1750°-1755°F FOR 5-10 MIN.
} H_2 ATMOSPHERE

TOTAL SHIM BUTT END LEAKS		
CYCLE	AGC *	ORNL **
1ST	27	55
2ND	0	0
3RD	1	4

* 4175 PSI BURST PRESSURE
** 4050 PSI BURST PRESSURE

Figure 25

Location of Leaks for Sectors 6 and 7

B. RESISTANCE WELDING INVESTIGATION

The resistance welding methods were developed for holding the U-tubes in the jacket grooves prior to furnace brazing. Scalloped specimens (Figure 26) were prepared and welding schedules were developed using the Sciakey Welding Machine located in the Manufacturing Division of LRP-AGC, Sacramento. The electrodes were modified by attachment of portable leads equipped with a ground clamp and a tip machined to the contour shown in Figure 27. Machine settings were established using 0.016 in. thick Type-347 stainless steel. Machine settings were monitored with an oscilloscope and the maximum shear tensile results obtained were 230 lbs. Nioro foil 0.001 in. thick placed between the stainless faying surfaces yielded 120 lbs. tensile shear values. Resistance-welding machine vendors were surveyed and a Model 51.# Stryco welder was puchased for the assembly of the full length contoured sectors and nozzles.

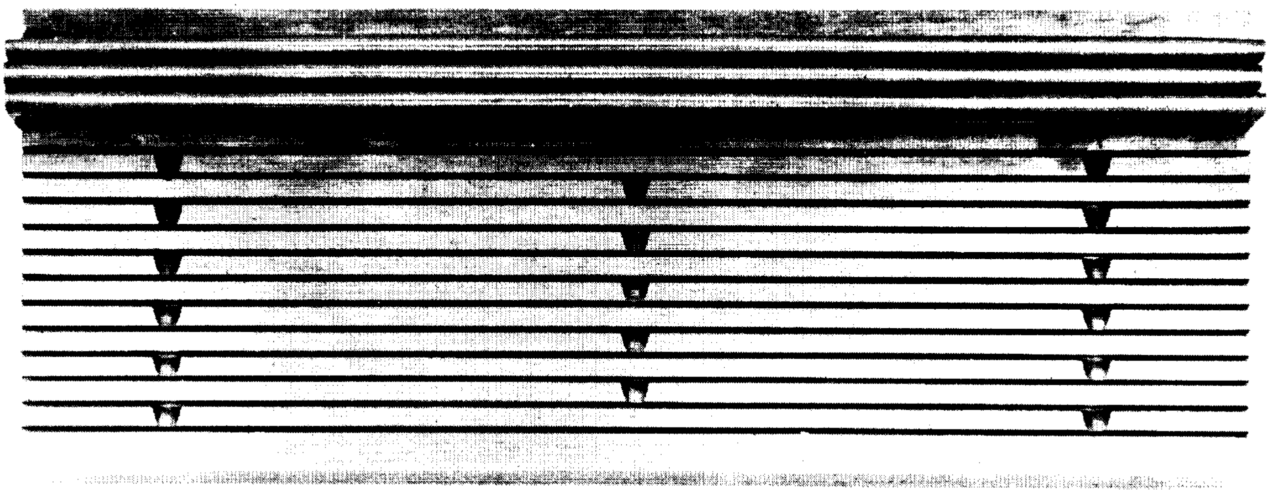


Figure 26

Scalloped Specimen for the Development of Resistance Welding Procedures

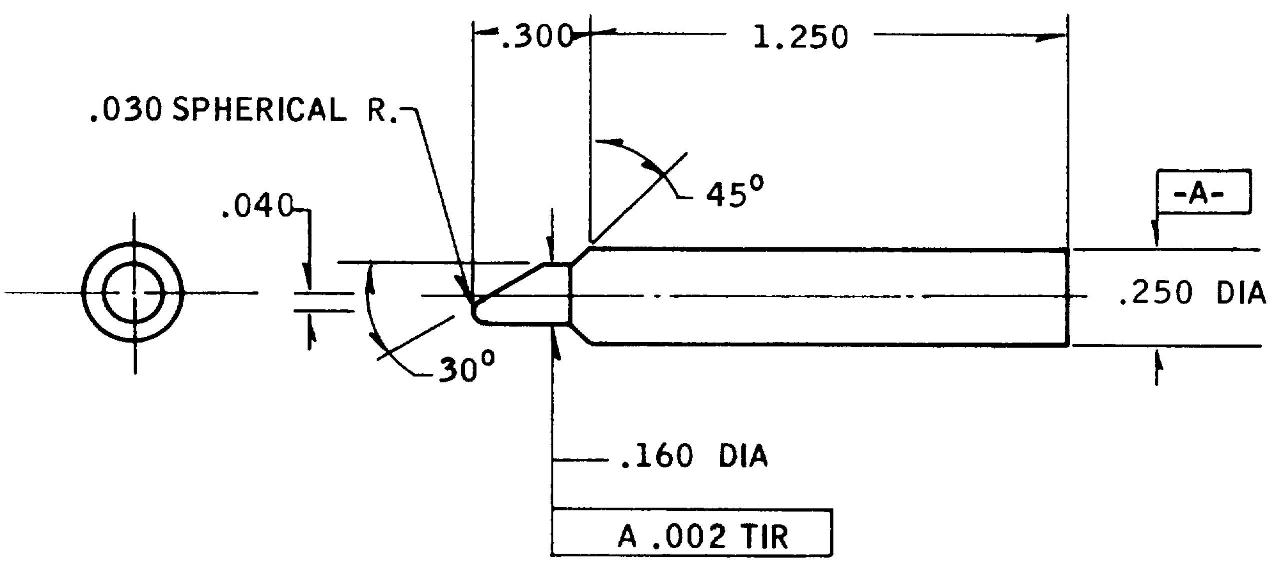


Figure 27

Spot Welding Tip for "U" - Tubes
(Scale 2:1, Illustration not classified)

C. CONTROLLED ENVIRONMENT ASSEMBLY AREA

The estimated four to six week tube layup and assembly time, for U-Tube nozzles, required a clean assembly area to reduce the possible entrapment of foreign material (such as dust) in the grooves. An industry survey and review of AGC facilities was accomplished, but acceptable assembly areas could not be located. AGC specification 46590 (Appendix B) was written to comply with the minimum requirements of proposed Federal Standard No. 209. The AGC specification includes the following requirements:

1. adequate lighting
2. positive internal room pressure
3. filtered air and dust count
4. humidity control (to prevent rusting of hand tools)
5. room temperature controls (for personal comfort)
6. room content and attire controls.

Pyromet Inc., San Carlos, California, designed and constructed a clean room to comply with the requirements of AGC Specification 46590.

D. TOOLING DESIGN

Assembly of the full length contoured sectors indicated a need for special tooling to facilitate braze alloy placement and tube installation. Tooling was designed for the following purposes:

1. Performed Braze Alloy Configurations

The basic configuration for the preformed foils is a "U" shape (Figure 28) for placement in the nozzle grooves, and a "V" shape (Figure 29) for placement around the shims that are driven between the tubes. Discussions with the supplier of the braze alloys, used on the NERVA U-tube nozzles, indicated that the desired shapes could be fabricated in the same manner as house rain gutters. A purchase order was released to Western Gold and Platinum, Belmont, California, to design and build a continuous foil forming machine, shown in Figure 30 and 31. Performance of the machine was acceptable and the desired shapes are now produced to close tolerance dimensions.

2. Braze Alloy Foil and Wire Spacers

Positioning of the braze alloy wires and foils adjacent to the nozzle grooves required the use of spacers placed into the nozzle grooves. The spacers for the sectors and NERVA Nozzle S/N-9 were cut from pressed, glass-reinforced, phenolic resin. These spacers shed during use and were not totally acceptable. Marquardt Corporation, Ogden, reports on the assembly techniques used on S/N-8 were reviewed and use of anozed aluminum spacers was noted. Aluminum spacers were machined to the configuration shown in Figure 31 and anodized, and successfully used for the assembly of NERVA Nozzles S/N's 22 through 28.

3. Coolant Tube-Leg Spacers

Spacers are required to force coolant tube legs against the groove walls to insure intimate faying surface contact during resistance welding operations. The tube-leg spacers also iron out longitudinal waviness in the tube legs and insure adequate clearance for the next tube leg, braze alloy foils, and shims. Spacers fabricated from 300-series stainless steel and machine-ground Starrett Stock were evaluated. The Starrett Stock spacers, machined to the configuration

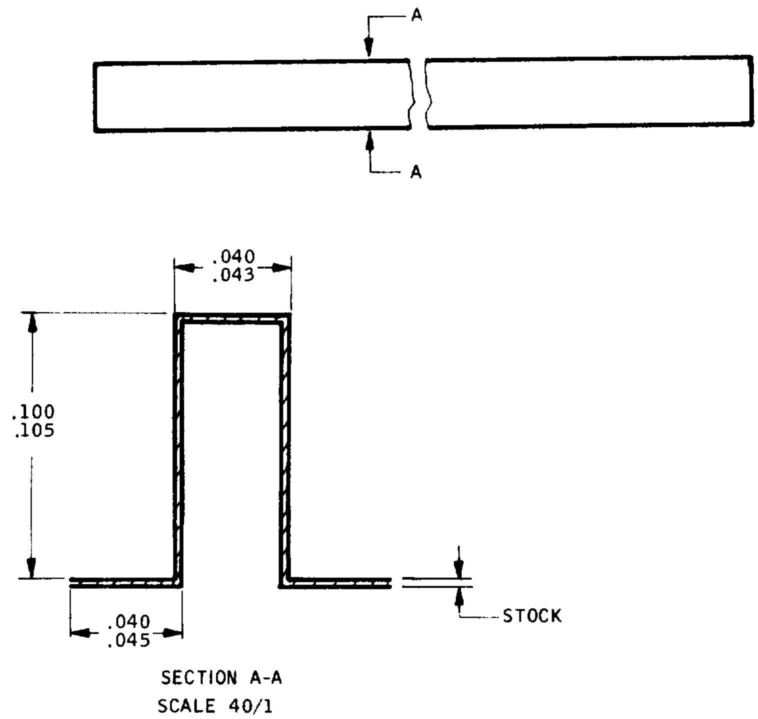


Figure 28

"U" Foil Configuration

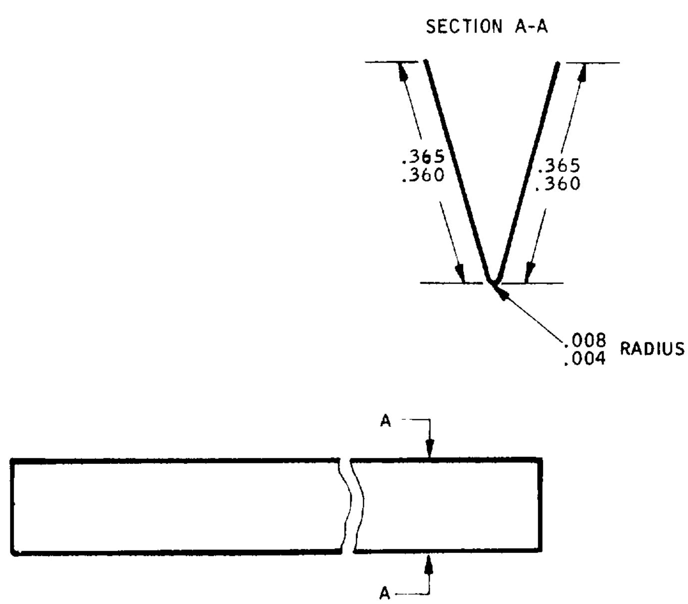
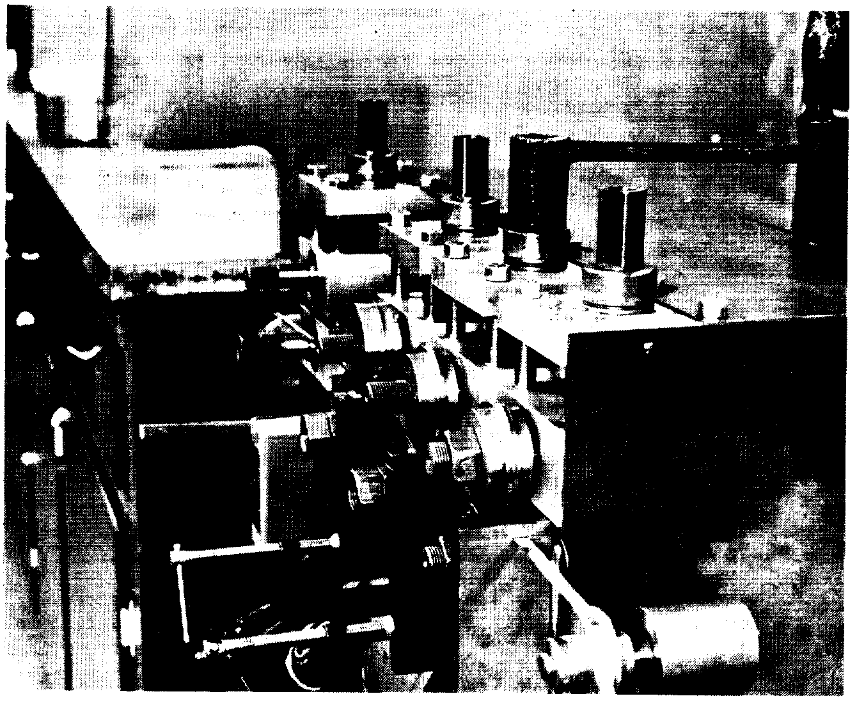


Figure 29

"V" Foil Configuration



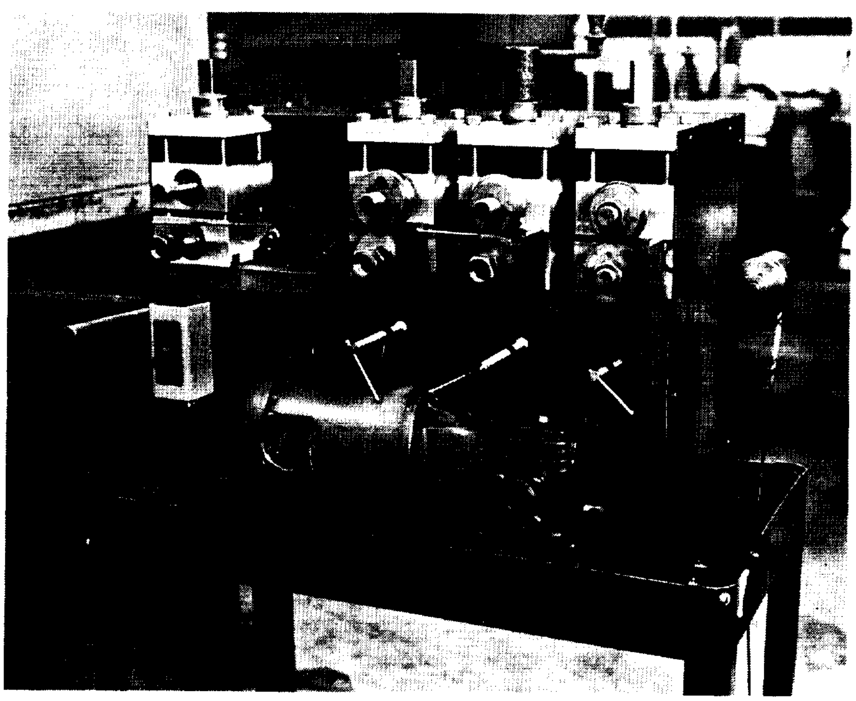


Figure 30

Continuous Foil Braze Alloy Preforming Machine

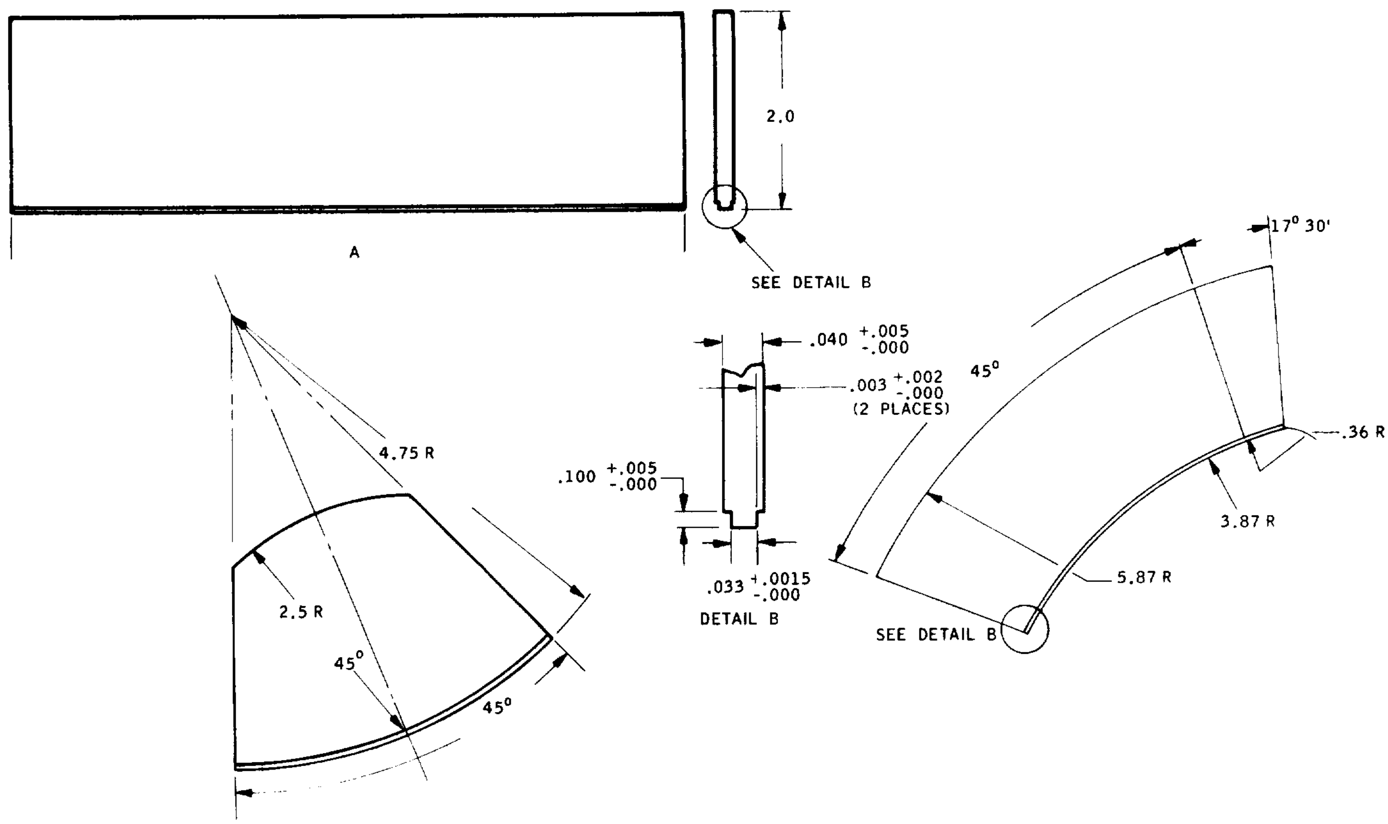


Figure 31

Anodized Aluminum Foil Spacers

shown in Figure 32 possessed adequate rigidity for positioning purposes and were selected for future NERVA nozzles.

4. Crown Height Gauges

To insure that the tube legs are bottomed in the grooves, gauges were designed (Figure 33) to determine actual crown heights. These gauges were not fabricated in time to use on NERVA nozzles assembled during this report period. A throat gauge was machined (Figure 34) from 6061 aluminum alloy and a 0.010-in. diameter "no-go" wire, held in a pin vise, was used for the assembly of nozzles S/N-22 through 28. The criteria for tube placement acceptance was that the wire could not be placed between the tube crown being installed and the crown of its nearest neighbor. All the tube crown heights in the throat area of NERVA Nozzles S/N-22 through 28 were held within the specified 0.010-in. variance.

5. Contoured Feeler Gauges

Feeler gauges were used to insure adequate clearance for tube legs and to remove foreign material from the jacket grooves prior to tube leg insertion.

6. Shim Driving Blanks

Expandable shim driving blanks were designed and fabricated (Figure 35) from 300-series stainless steel. Contoured blanks are provided for driving the contoured throat and knuckle shims. These blanks support the shims and provide the required rigidity for insertion of the shims between the tubes. Blanks fabricated from other metallic materials, and made from three pieces joined by mechanical and/or welding methods, were evaluated during sector fabrication. They were determined unsuitable. The machined driving blanks are acceptable for repeated use. However, in forcing the shims into minimum tolerance areas between the tubes the driving blanks are damaged and/or worn at a rapid rate and must be replaced frequently.

7. Furnace Brazing Fixture

Fixturing requirements were reviewed with Pyromet personnel and ring-type fixtures were designed (Figure 36) to support the nozzle at the pressure vessel flange. These fixtures performed acceptably during the annealing and brazing of NERVA nozzles.

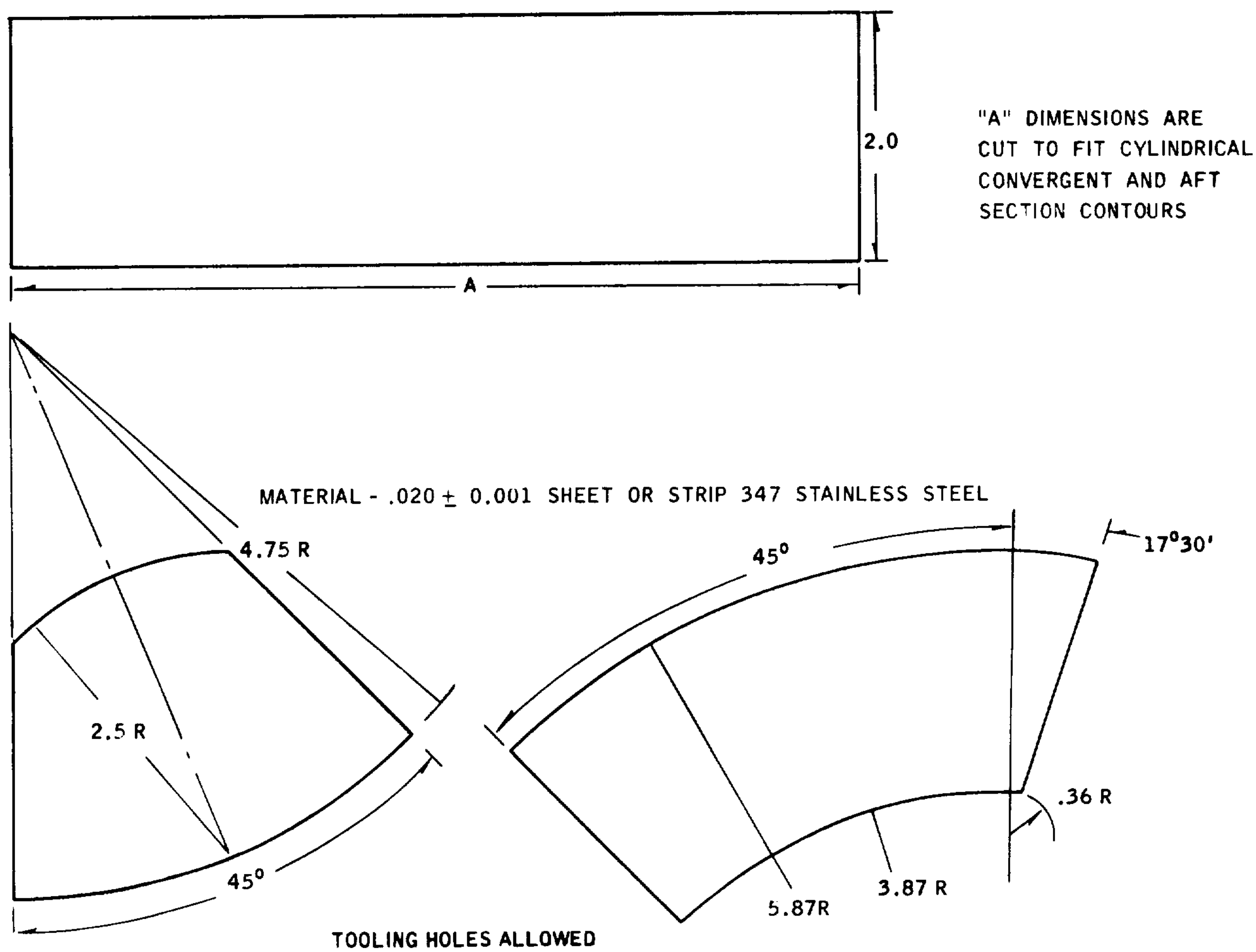


Figure 32

Coolant Tube Log Spacers

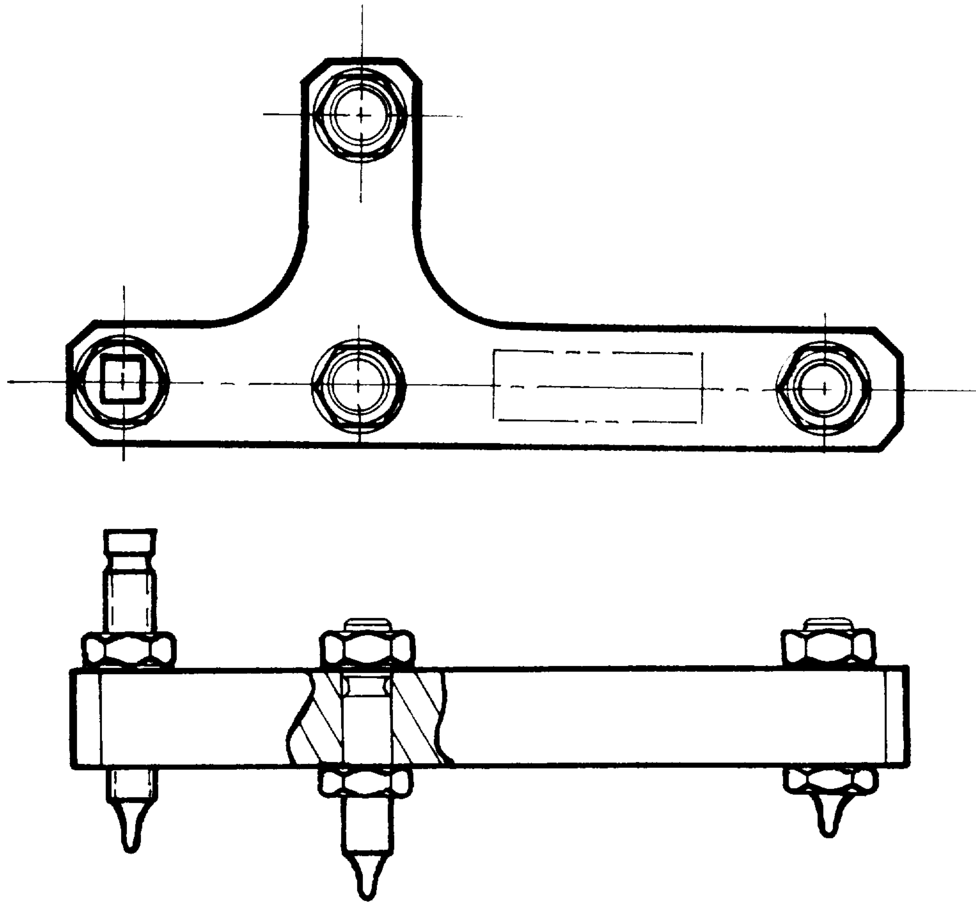


Figure 33

Crown Height Gage for the Cylindrical Section

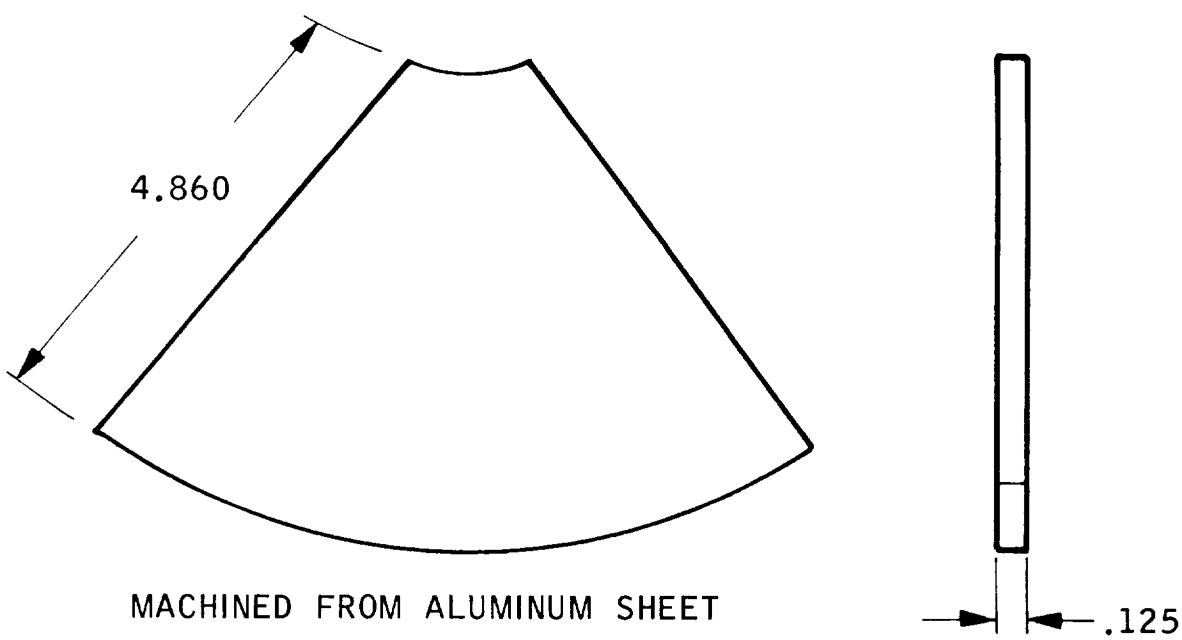


Figure 34

Pyromet Throat Gage

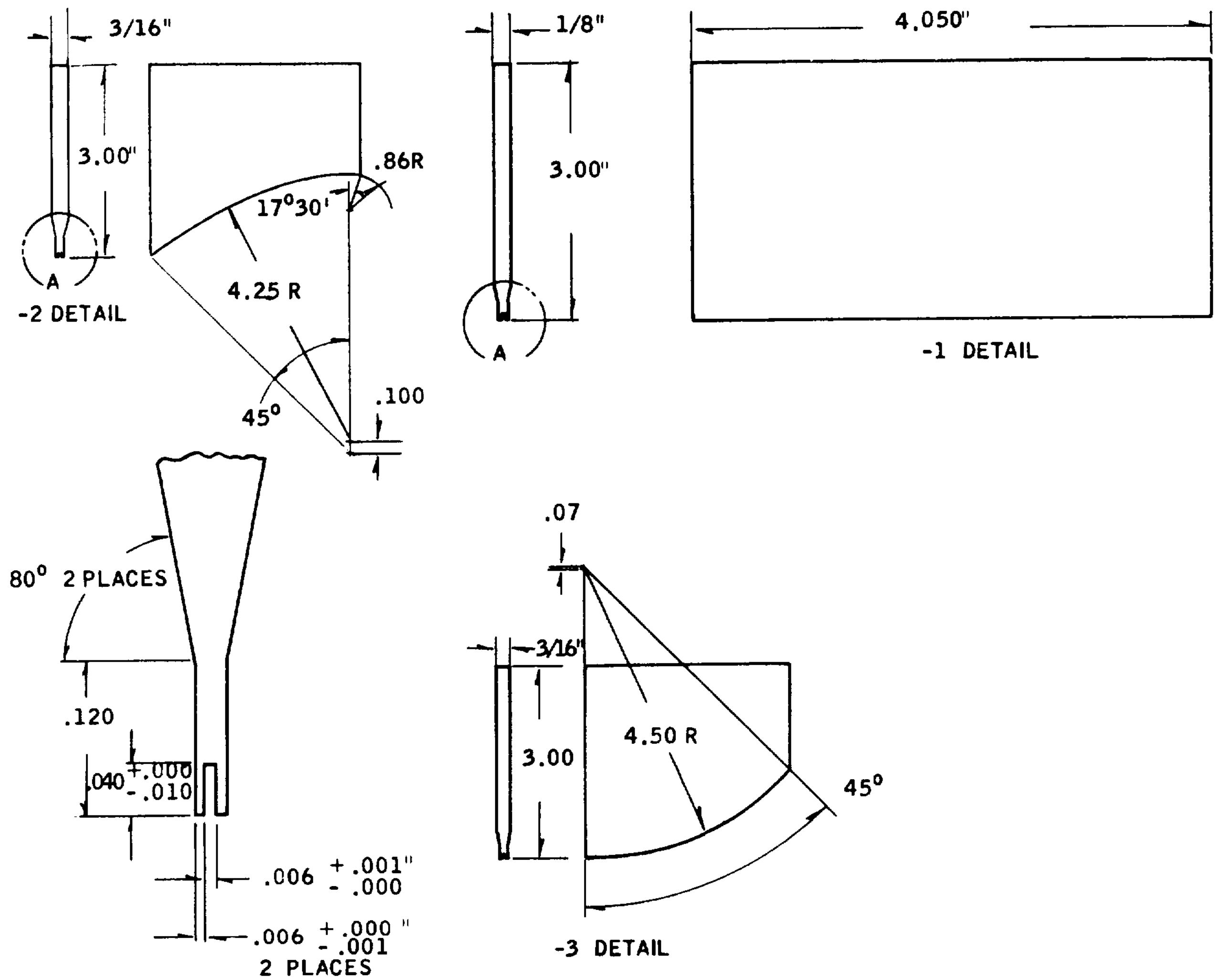


Figure 35

Shim Driving Blanks

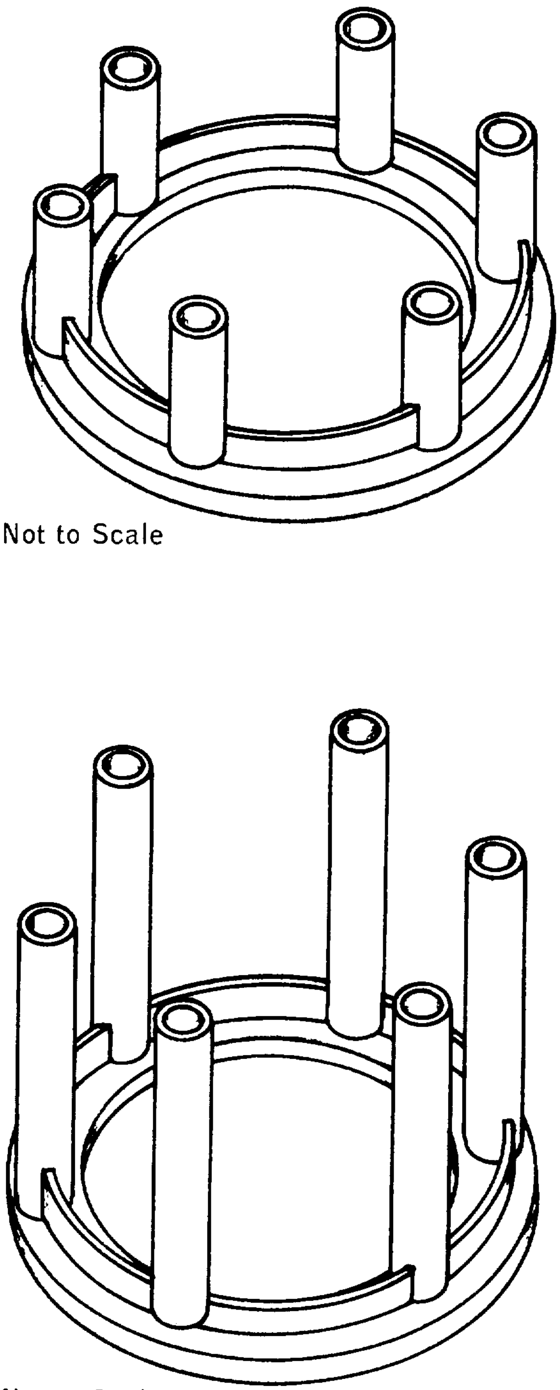


Figure 36

Furnace Brazing Fixtures

8. Protective Atmosphere Manifolds

Forward and aft manifolds were designed and fabricated to preheat and deflect the protective hydrogen to the internal coolant tube walls (Figure 37).

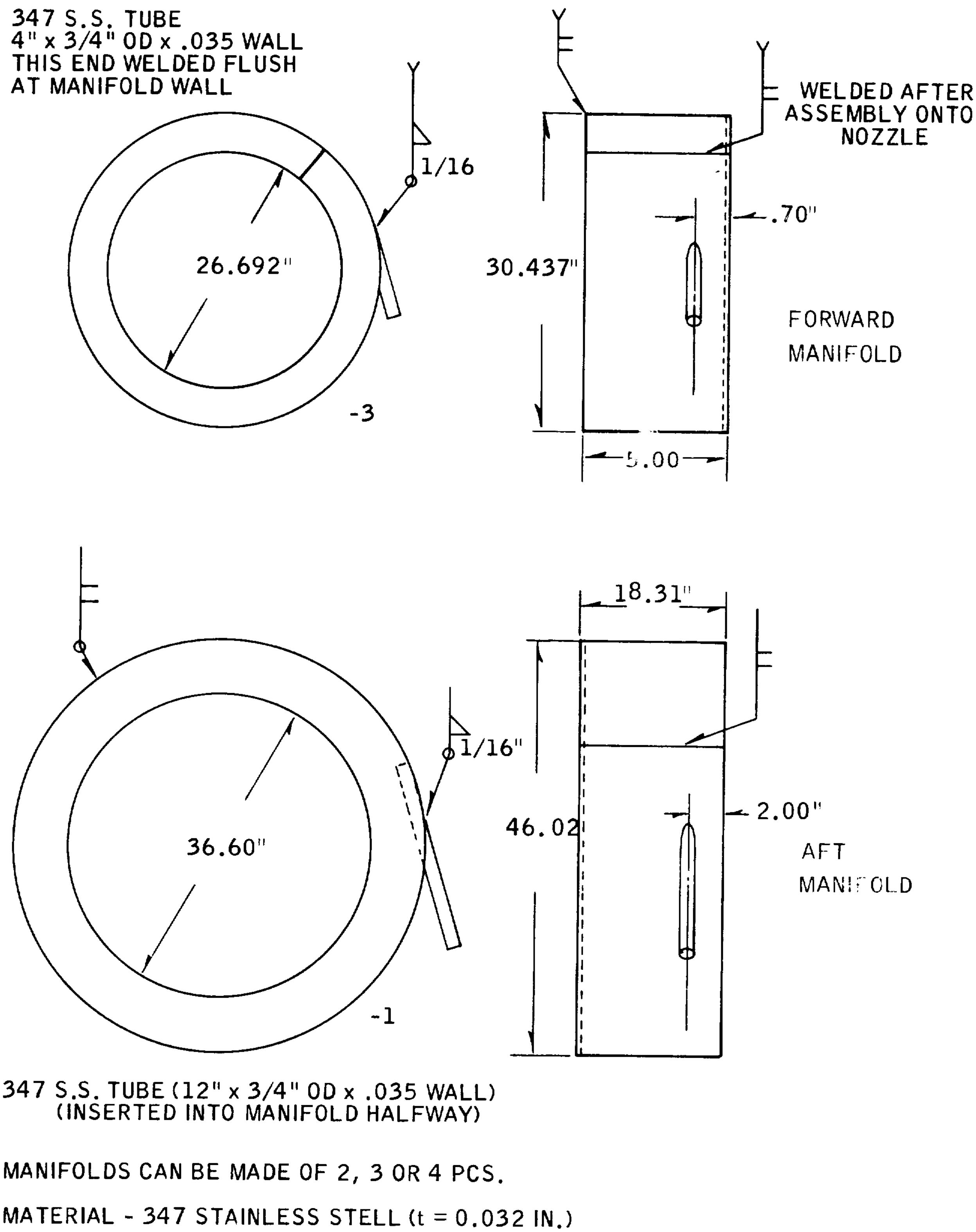


Figure 37

Protective Atmosphere Manifolds

E. LEAK REPAIR PROCEDURES

Nozzles and test sectors are subjected to low pressure leak checks after furnace brazing. Leaks indicated are torch-repaired prior to hydro tests. The following procedures were developed to effect a pressure seal between the tubes at indicated leak areas:

1. Sector Localized Leak Repair Methods

All sectors were repaired using an oxy-acetylene torch, Easy Flow 45 braze alloy, and Handy and Harmon High Temperature Flux. All leak areas were coated with flux prior to the application of the braze alloy. Flux residue was removed by hand wire brushing and water rinse. This procedure was acceptable for sealing leaks in all test sectors.

2. NERVA Nozzle S/N-8 (Marquardt) Leak Repair Method

The Marquardt Nozzle, S/N-8 did not incorporate shims between the tubes, and major tube-to-tube leakage was detected after furnace brazing. Nioro braze alloy, 0.020- to 0.030-in. diameter, was resistance tack-welded between each tube-to-tube junction the full length of the nozzles. All tube-to-tube joints were generously coated with Nicro-braze flux. The cone of a reducing flame from an oxy-acetylene torch was impinged directly on the Nioro wire. Flux residue was removed with hot water and hand scrubbing with a small bristle brush. The Marquardt developed repair method produced a cap between the tubes and effectively seals gross leak areas; however, the corrosive flux trapped under the cap cannot be removed.

3. NERVA Nozzle S/N-9 (Aerojet) Repair Procedure

A development program was initiated by the Aerojet Fabrication Engineering Department, Manufacturing Engineering Division, to establish torch repair procedures for NERVA Nozzle S/N-9, using sections from full length Sectors 2, 3, and 4. The results of this program indicated BT alloy (72 Ag 28 Cu) possessed the best application characteristics and this alloy was specified for the repair of NERVA Nozzle S/N-9.

The leak check after furnace brazing revealed 261 shim butt-end leaks, 90 forward flange leaks, and six thermocouple pass-through leaks (Figure 38). All

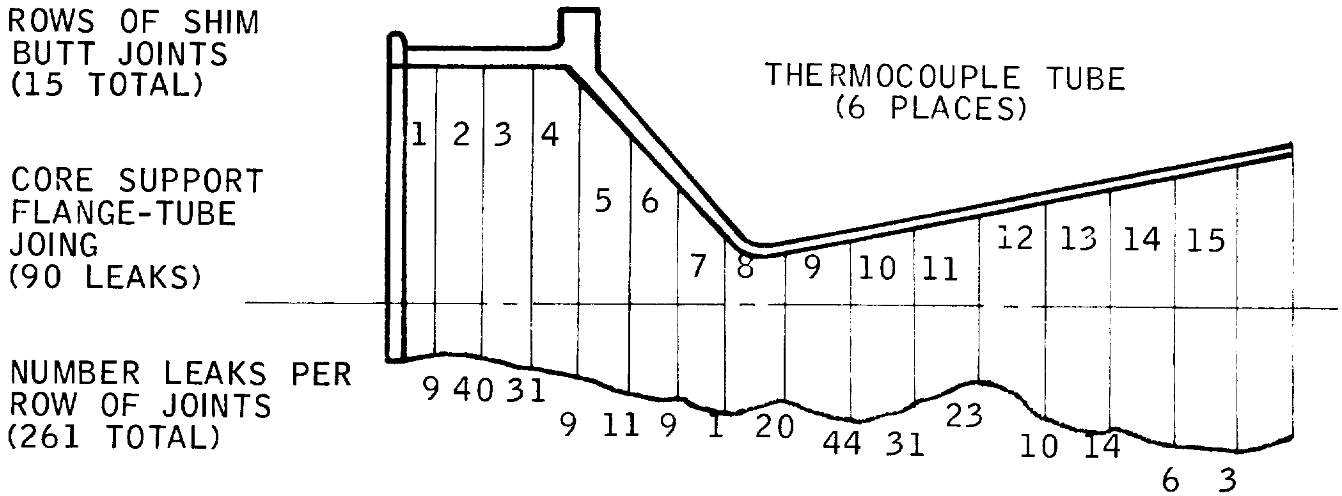


Figure 38

Location of Leaks for NERVA Nozzle, S/N-9

Figure 39

Coolant Tube Cracked during Localized Torch Repair
(NERVA Nozzle, S/N-9)

leaks except the shim butt-end leaks at the cylindrical and convergent section were sealed using BT alloy and a 50-50 mixture of Eutectic Black Flux and Handy and Harman Hi-Temperature Flux. Attempts to seal the shim butt-end leaks at the cylindrical and the forward half of the convergent section resulted in cracked tubes (Figure 39) attributed to over-heating. The tangency points of the tubes in these areas are close to the jacket, which acts as a heat sink. Adequate heat input to effect the seal overheats and cracks the tubes. The cracks were heliarc-welded using Type-349 stainless steel filler material; and the remaining leaks were bridged by applying a fillet of BT alloy from the forward flange to the second shim butt-end in the convergent section. The repair method established for NERVA Nozzle S/N-9 was not acceptable from the standpoint of time consumed and the hardware damage involved.

4. NERVA Nozzle S/N-22, Leak Prevention Procedure

The problems encountered and the time required to manually torch braze the shim butt-end leaks on NERVA U-Tube Nozzle S/N-9 indicated that additional furnace braze cycles should be considered. A program was initiated to evaluate duplex alloy placement at the shim butt to prevent leakage at these points. This method incorporates a high melting point alloy as the filler material and a low melting point alloy that becomes sluggish in wide clearances, through alloying mechanisms with the filler material, and is retained in the potential leak area. The method of alloy placement evaluated were mechanical mixtures and duplex alloy overlays placed at the prepared shim butt-ends and down the full lengths of the joint. The specimen configurations is as shown in Figure 40. The low melting point alloy selected was Nioro, to be compatible with the 1825°F second braze cycle temperature established for NERVA Nozzle S/N-9. The high melting point alloys investigated were Nicoro (35 Au, 62 Au, 3 Ni), Palniro-4 (30 Au, 34 Pd, 36 Ni), Palniro-1 (50 Au, 25 Pd, 25 Ni), Palniro-7 (70 Au, 8 Pd, 22 Ni), and pure nickel powder. Specimens were cycled at 1850, 1825, and 1800°F to determine the degree of sensitivity of the duplex alloys to braze temperature variations. Alloy mixture ratios of 2:1, 1:1, and 1:2 were investigated. All specimens were visually examined and the following were observed:

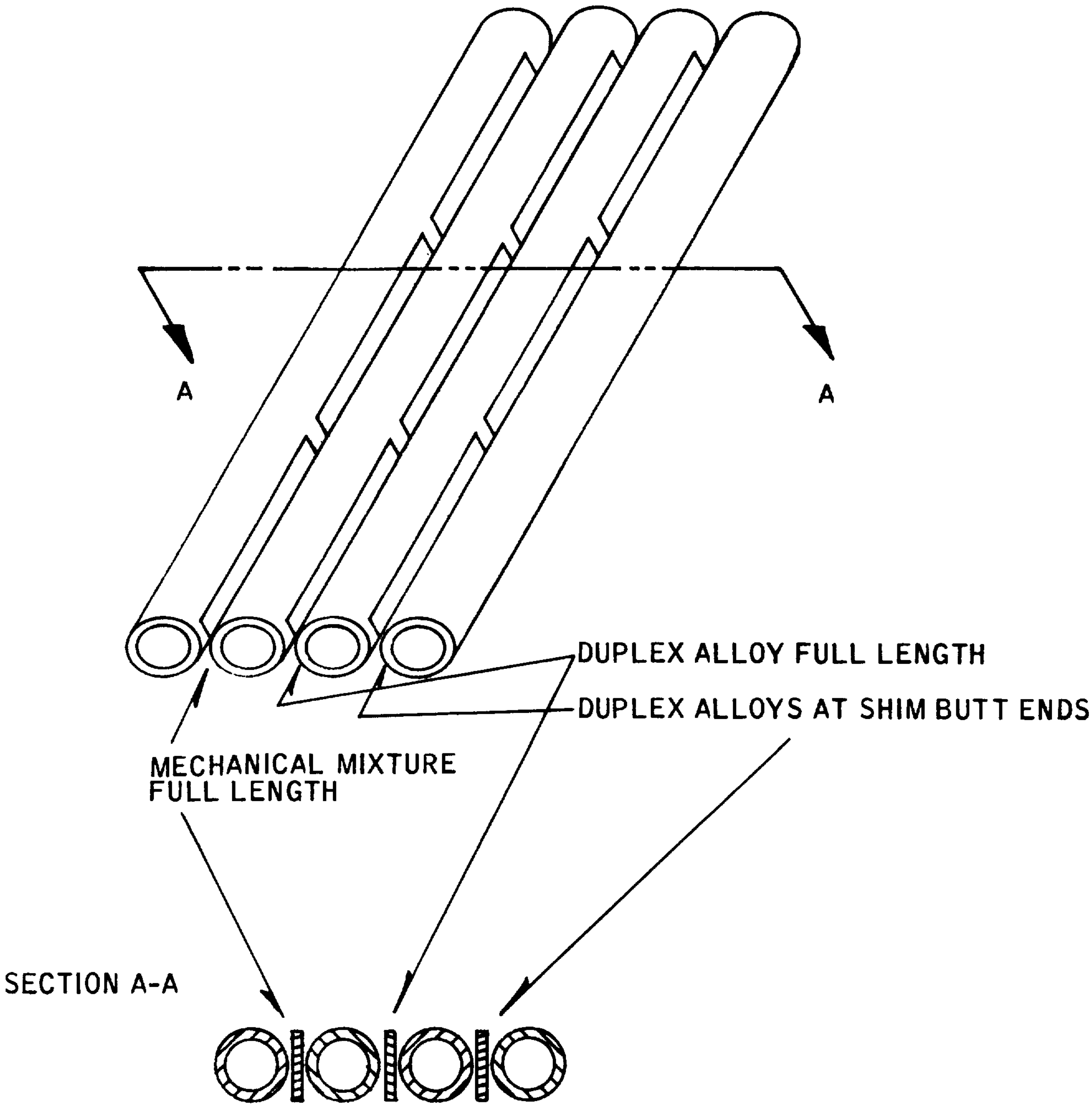


Figure 40

Specimen Configuration for Leak Prevention Investigation

a. The mechanical mixtures had a rough sintered appearance and excessive alloy runoff was noted.

b. The nickel filler powders did not stay in the wide shim butt-end joints; being less dense than the Nioro alloy, the nickel powder floated out of the joints leaving void areas.

c. The filler materials, and Nioro alloy applied to the joints for the full length of the specimens,snow-balled resulting in uneven joint coverage.

d. The AGC-7 material applied as a fillet, then overlayed with Nioro braze alloy, was less sensitive to temperature and alloy ratio variations than the other filler material combinations investigated.

The AGC-7-Nioro overlays were applied to all shim butt-ends of Sectors 6 and 7 after completion of the first furnace braze cycle. These sectors had a total of 82 shim butt-end leaks which were successfully sealed during the second cycle. However, gross side wall leaks were observed in Sector 7 after the second cycle. Sectors 6 and 7 were then cycled for the third time with Nicoro-80 braze alloy applied to all tube-to-tube joints. A total of five minor sidewall leaks were detected for both sectors after the third and final furnace braze cycle. The five leaks were hand repaired using BT alloy and an oxy-acetylene torch.

The braze alloy overlay procedures and the three furnace brazing cycles developed on Sectors 6 and 7 were applied to NERVA Nozzle S/N-22. Approximately 40 leaks were detected after the second braze cycle which were reduced to a total of 13 leaks after the third braze cycle. These leaks were hand repaired using BT alloy and an oxy-acetylene torch. The reduction of leaks on S/N-22, with respect to S/N-8 and S/N-9, justifies the use of the additional furnace cycles.

F. ASSEMBLY AND BRAZING PROCEDURES

1. Marquardt NERVA Nozzle S/N-8

NERVA Nozzle S/N-8 was fabricated by The Marquardt Corporation, Ogden, Utah, using joint configuration and braze alloy placement technique shown in Figure 41 (Reference 5). The nozzle groove side walls and coolant channel faying surfaces were grit-blasted with Nicro-braze,AMS 4775A, 150-mesh powdered alloy. Assembly was accomplished in a clean room complying with the requirements of Tech Order 00-25-203 Class I. A 0.002-in. thick Nioro braze alloy foil was tack resistance-welded the full length of one leg of each tube. The width of the braze alloy foil was equal to the crown height of the tube. Braze alloy foil 0.004-in. thick by 0.030-in. wide was tack resistance-welded to the bottom of each jacket groove.

The chamfered face of each groove was loaded with 0.010-in. by 0.030-in. wide Nioro braze alloy strip tack resistance-welded at 1/4-in. intervals. The tubes were installed in the jacket grooves and one tube leg was tack resistance-welded to the groove wall using a Unitek capacitor discharge welding machine. The tube-to-forward-flange interfaces were circumferentially loaded with 0.002-in. thick foil and 0.025-in. diameter Nioro braze alloy wire. A 0.030-in. diameter Nioro braze alloy wire was tack resistance-welded between each tube-to-tube joint at the aft end cap extending 12 in. toward the throat.

The assembled nozzle was placed in a retort, with the forward end down, and brazed in a gas-fired furnace at 1825 to 1850°F for five minutes. Up to 1500°F the heating rate was not controlled. At 1500°F the part temperature was stabilized for 30 minutes. The part temperature was then raised in 100°F increments to 1700°F, held for 10 minutes, then raised to 1740°F. Then, part temperature was raised, in 20°F increments, to 1825°F and held for five minutes. The cooling rate from the braze-temperature to room-temperature was not controlled. After furnace brazing, all tube-to-tube junctions were axially loaded with 0.020 to 0.030-in. diameter Nioro wire and torch-brazed as previously described in this report. The nozzle was then final machined, subjected to hydro leak and proof-test, and shipped to AGC Sacramento for chemical firing.

2. Pyromet NERVA Nozzles S/N-9 and S/N's 22 through 28

NERVA Nozzles S/N-9 and S/N's 22 through 28 were assembled and brazed at Pyromet, Inc. (of San Carlos, California), in accordance with AGC Specification 90006 (Appendix C and Pyromet Procedures 101 (Appendix D).

The alloy placement for NERVA Nozzle S/N-9 is shown in Figure 42, for S/N's 22 through 26 in Figure 43, and for S/N's 27 and 28 in Figure 44. Deviation from the assembly procedures used for S/N's 22 through 26 were required to compensate for groove and tube wall dimensions and will be discussed separately.

a. Procedure

(1) S/N's 22 through 26:

The grooved jackets were subjected to a HNO3-HF etch at AGC Sacramento prior to shipment to Pyromet, San Carlos. At Pyromet the cleaned nozzles were unpackaged, placed in an assembly cart and moved into the clean room. Preformed braze alloy was releaved in scalloped locations (Figure 46), placed on the anodized aluminum spacers and inserted into the grooves (Figure 46). Braze alloy wire 0.020 in. in diameter was placed on each side of the spacers and resistance welded in place (Figure 47).

The foil spacers, shown in Figure 48, were removed and the preloaded grooves (Figure 49) were dimensionally-inspected with a 0.036-in. wide feeler gage. Tubes were installed (Figure 50) and tube leg spacers inserted as shown in Figure 51. The tube legs were resistance welded (Figure 52) at the scalloped locations (Figure 53). Tube crown heights were inspected (Figure 54) to insure a maximum variation of 0.010 in. between tube crowns at the throat. The tube leg spacers were removed and alignment of the thermocouple pass through dimples, in the convergent section, was verified (Figure 55). After tube installation was complete braze alloy foil 0.001-in. thick was resistance welded to the shims which were then inserted in the shim driving blanks, as shown in Figure 56. The preloaded shims were driven between all tube-to-tube joints, as shown in Figures 58 and 59. The end caps were welded to the core support flange, and at the aft end of the tubes. The assembled nozzle was placed in the retort on a ring fixture with the aft end down, and furnace brazed at 1825 - 1850°F for 10 minutes in a hydrogen protective atmosphere.

After furnace brazing the nozzle was removed from the furnace and the duplex braze alloy powder applied at the shim butt ends (Figure 59). Nioro braze alloy powder was then applied at the tube-to-tube junctions at the core support flange (Figure 60). The nozzle was placed back in the retort and furnace brazed at 1800 - 1825°F for ten minutes, with the forward end down. After the second cycle the nozzle was removed from the furnace and Nicoro-80 braze alloy powder was applied between all tube-to-tube joints; and it was furnace brazed for the third and final time at 1775 to 1750°F for ten minutes. The brazed nozzle was then moved to the clean room for visual and dimensional inspection (Figure 61) prior to shipment to AGC Sacramento.

(2) S/N-9:

Nozzle S/N-9 was the first NERVA nozzle assembled, and as expected unique problems were encountered. The assembly and brazing procedure was the same as for S/N's -22 through -26 with the following exceptions (See Appendix E):

(a) Alloy Placement

S/N-9 was grooved prior to completion of the braze development program, consequently the narrow groove widths of .036 - in. to .039 - in. precluded the placement of braze alloy foil in the groove. The tube leg faying surfaces for S/N -9 were grit blasted using a nickel-chronium-silican-boron hard-surfacing (AMS 4775) - 50 + 200 mesh powder to prevent zero clearance in the shear joints. The internal tube walls were protected with silicon rubber insert during grit blasting operation. Nioro braze alloy wire of 0.020-in. diameter was resistance-welded adjacent to each side of the groove using pressed phenolic resin spacers for positioning purposes.

(b) Assembly

Tube widths at the points of tangencies (nine inches aft of the throat) exceeded the maximum allowable drawing dimensions. After installation of 40 tubes adequate clearance was not available for installation of the 41st tube. The 40th tube, and each additional tube, was reworked just aft of the throat during installation. Each accessible tube leg was forced normal to the band by placing a hard wood block adjacent to the tube and tapping the block with a plastic hammer, after the tube had been installed. During the shim driving operation, it was noted that just aft of the throat in the troublesome area,

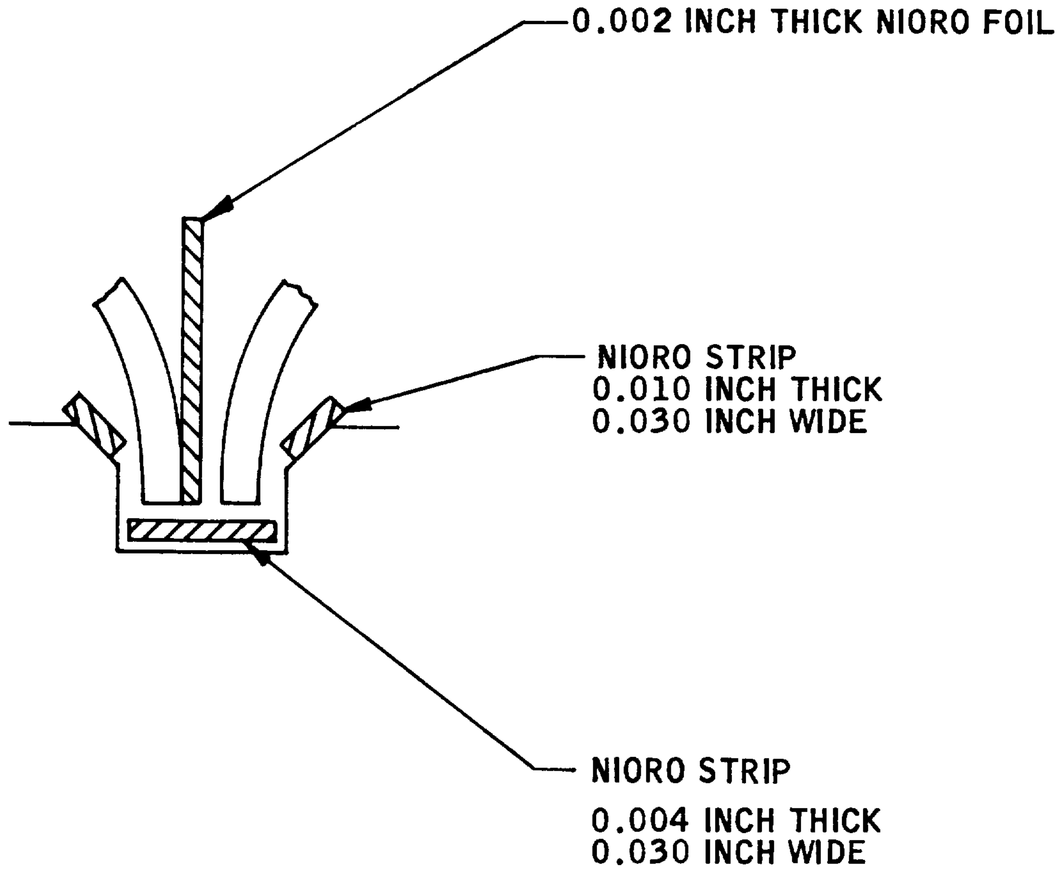


Figure 41

Braze Alloy Placement for NERVA Nozzle S/N-8
Assembled and Brazed at Marquardt Corp., Ogden, Utah

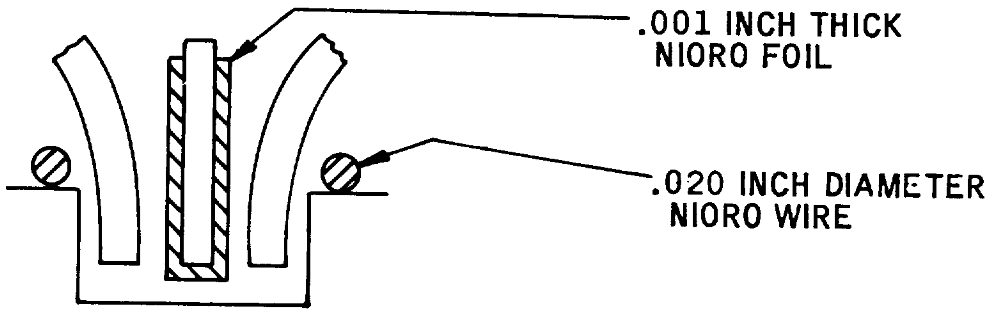


Figure 42

Braze Alloy Placement for Nozzle S/N-9

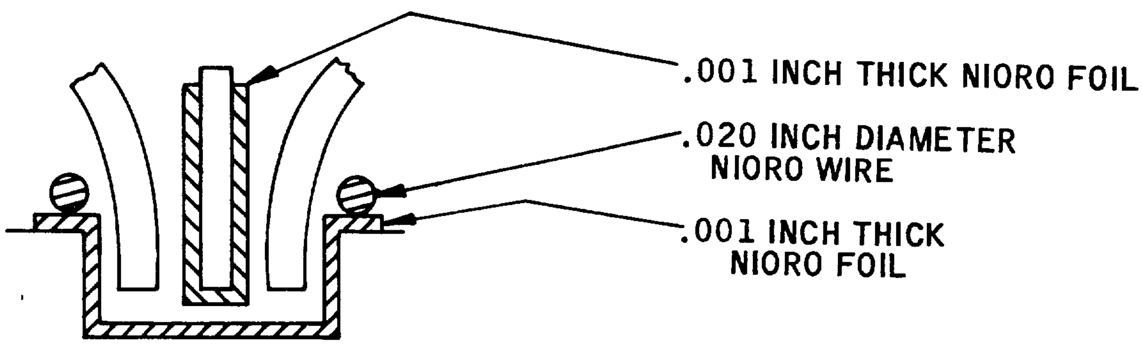


Figure 43

Braze Alloy Placement for Nozzles S/N-22 thru 26

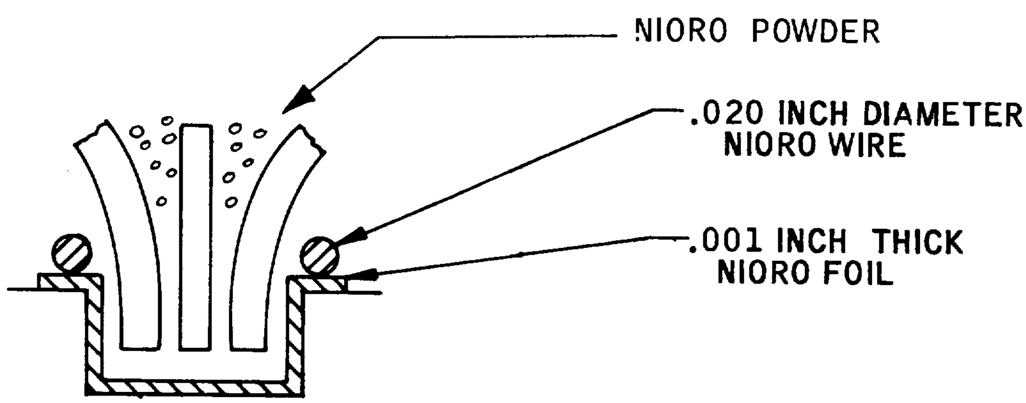


Figure 44

Braze Alloy Placement for Nozzles 27 and 28

Figure 45

Relief of the Braze Alloy Foil in the Scalloped Area

Figure 46

Inserting the Braze Alloy Foil into Annodized Aluminum Fo

Figure 47

the Grooves using the
il Spacers

Braze Alloy Foil and Wire being Resistance Welded in Place

FOLDOUT FRAME 2 57.2

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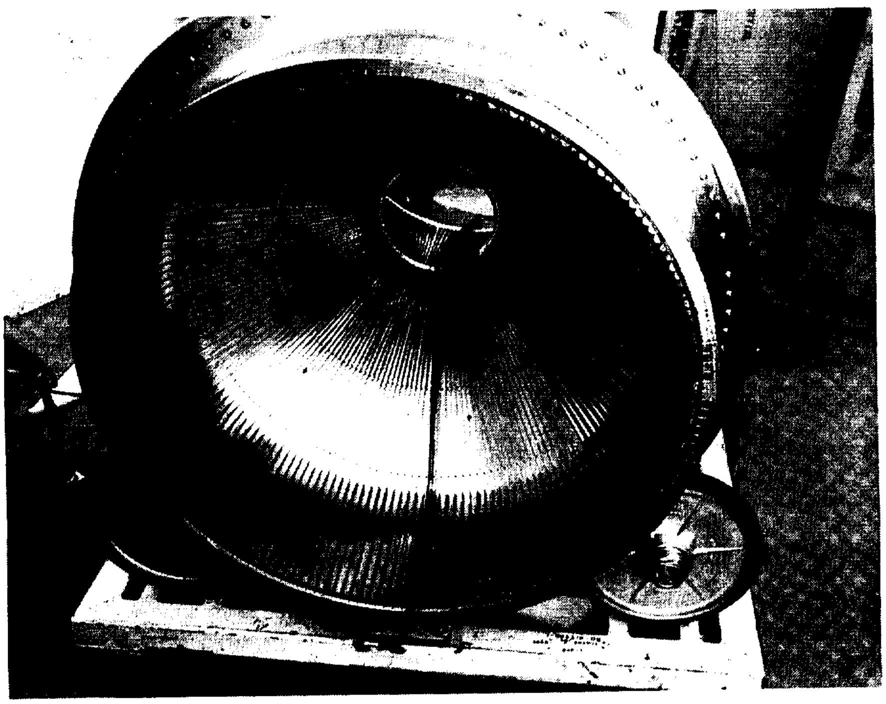


Figure 48

The Forward End of the Nozzles prior to Removal of the Foil Spacers

Figure 49

Grooves Loaded with Braze A

FOLDOUT FRAME 1

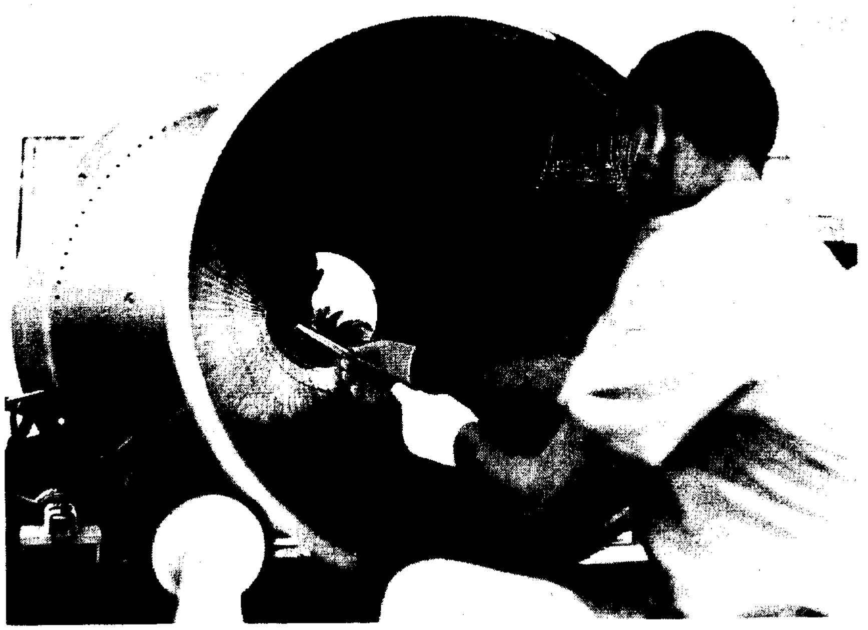


Figure 50

Installation of Coolant Channels

lloy Foil and Wire

FOLDOUT FRAME 2

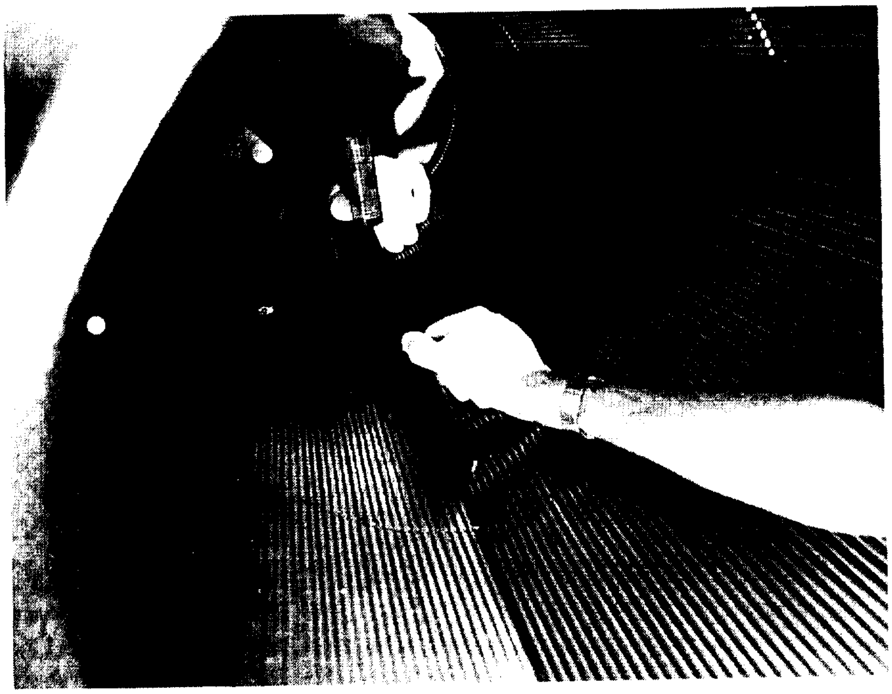


Figure 51

Insertion of the Tube-Leg Spacers

Resistance Welding

59-1

FOLDOUT FRAME 1

Figure 52

the Tube-Legs to the Groove Walls

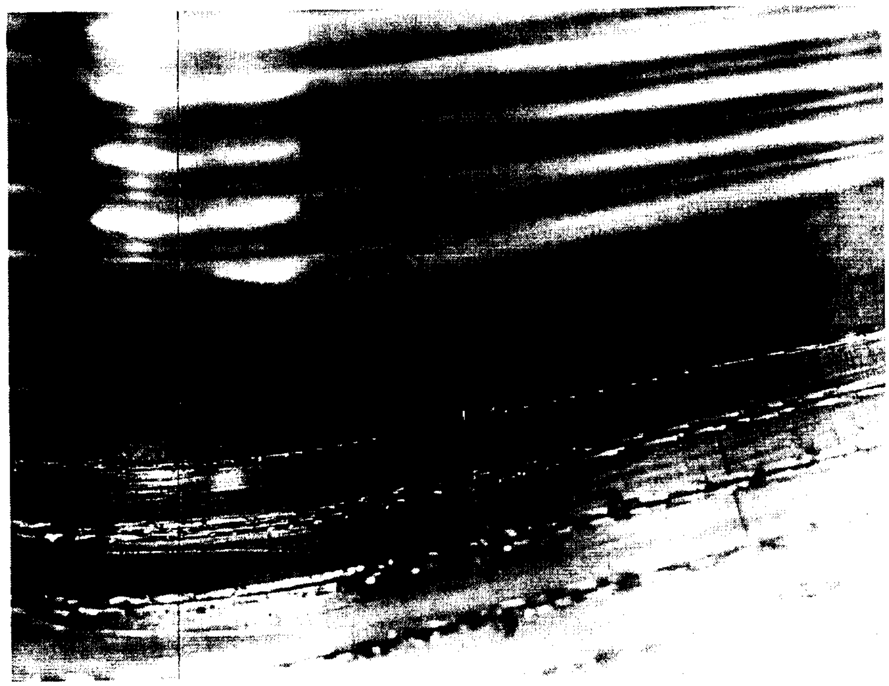


Figure 53

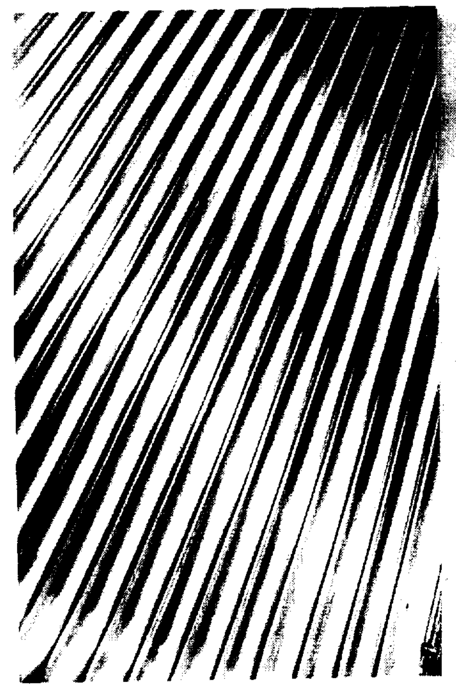
Scalloped Location for Resistance Welds

FOLDOUT FRAME 2 59.2

[redacted]

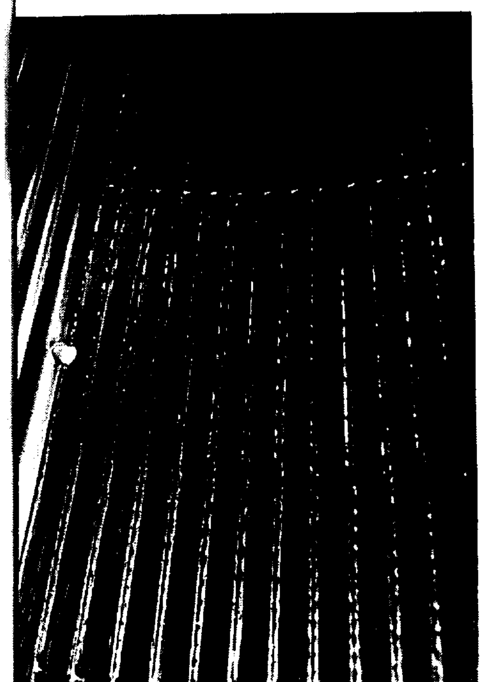
Figure 54

Inspection of the Tube Crown Locations at the Throat



Fi

Installed Tubes Showing a T



gure 55
hermocouple Pass through Location

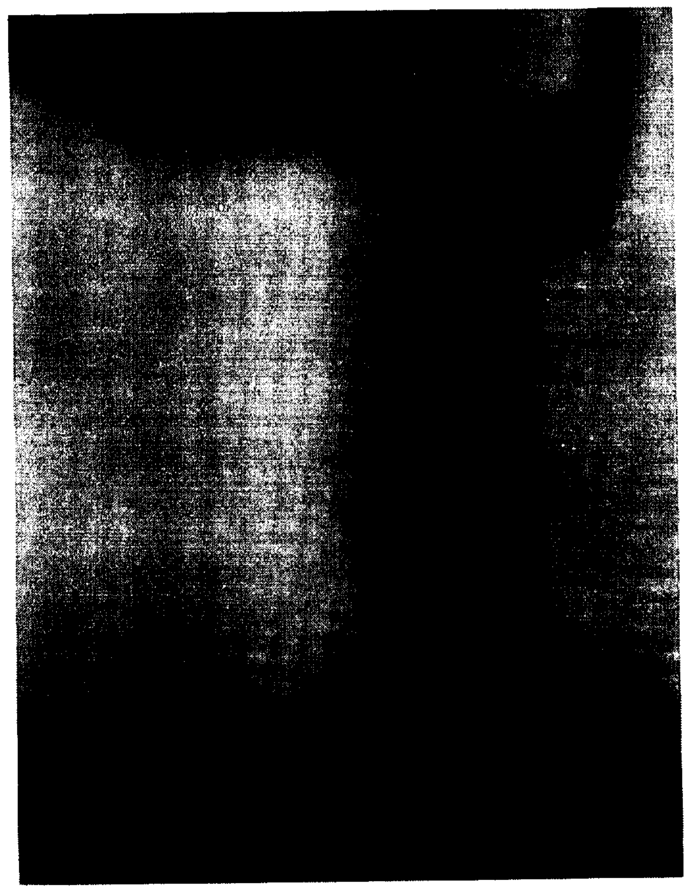


Figure 56
Shim Driving Blank and a Preload Shim
prior to Insertion between the Tubes

FOLDOUT FRAME 2

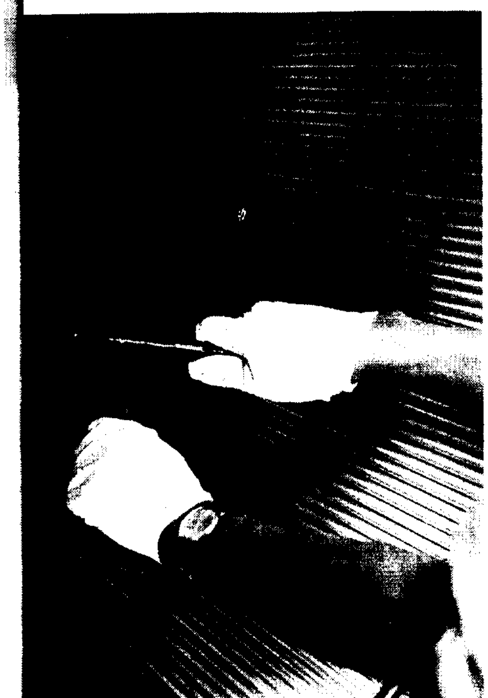
Figure 57

Installation of the Shims between the Tubes Viewed Aft through the Throat

Figure

Installation of Shims between

FOLDOUT FRAME 1



e 58
the Tubes in the Aft Section

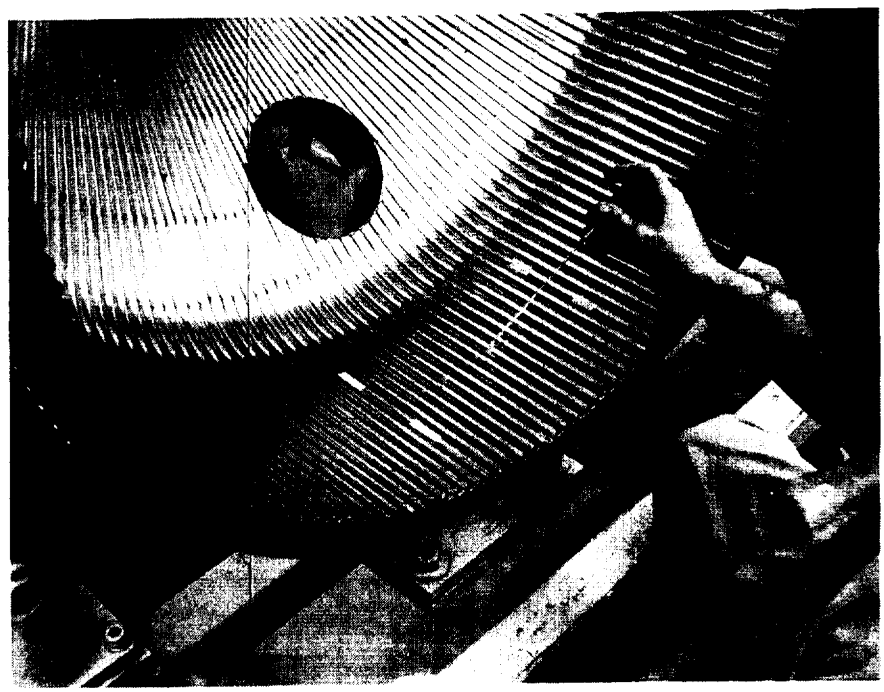


Figure 59
Application of the Duplex Alloy at the Shim Butt Ends

FOLDOUT FRAME 2

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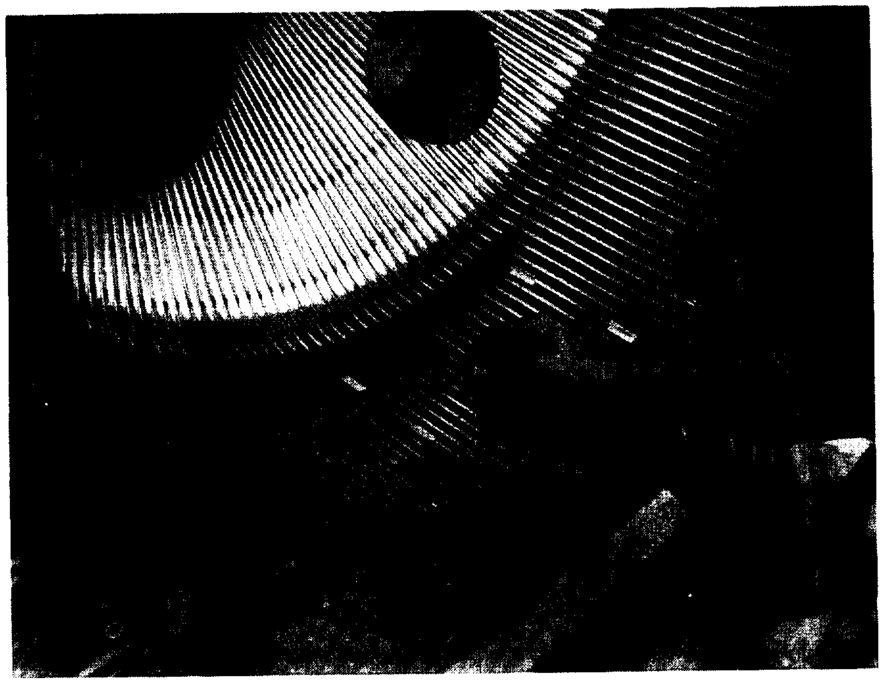


Figure 60

Application of Powdered Nioro Braze Alloy

at the Core Support Flange

FOLDOUT FRAME 1

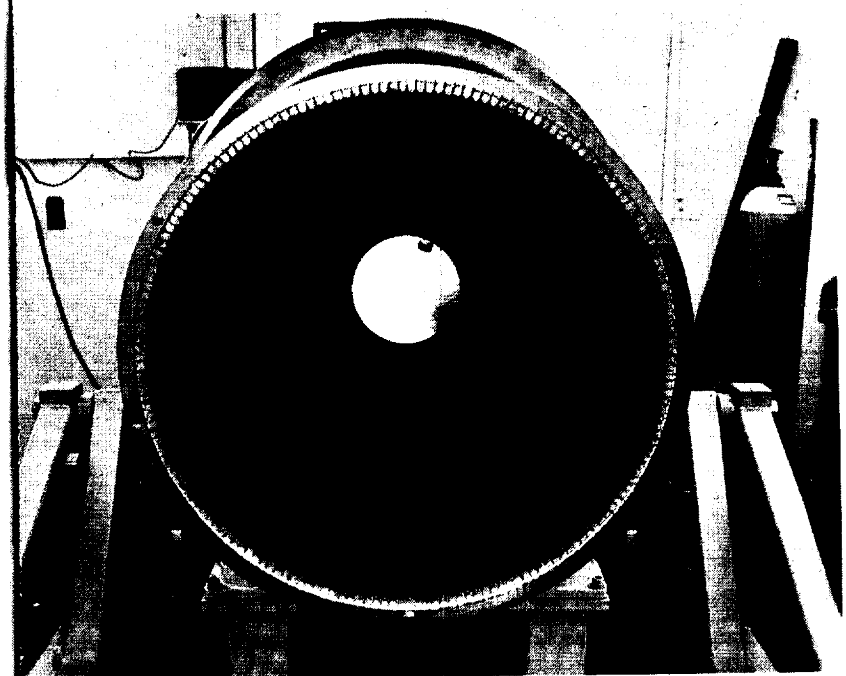


Figure 61

Aft View of the Furnace Brazed Nozzle
prior to Shipment to AGC-Sacramento

FOLDOUT FRAME 2

~~CONFIDENTIAL~~

some tube crowns would raise and be higher than their neighbors. The high tubes were forced back into their proper positions by placing a 1/8-in. thick hard rubber strip over the high tube and lightly tapping the strip with a plastic hammer. These tubes maintained their required positions during the braze cycle as no excessively high tubes could be detected aft of the throat after furnace brazing.

There were dimples in the thermocouple tubes slightly forward, with respect to the jacket thermocouple pass-through, consequently the thermocouple tubes could not be correctly positioned axialy. This condition resulted in the thermocouple tubes being 0.010 to 0.014-in. high at the throat with respect to their closest neighbors. This condition was minimized on subsequent nozzle jackets of having the thermocouple pass-through counter-bored.

Nozzle S/N-9 incorporated a machined core support flange to support the tube crowns at the forward end rather than individual tube end caps. Hence, the assembly and brazing vendor did not weld on the forward end of the nozzle.

(c) Furnace Cycles

The first cycle was accomplished at 1825 to 1850°F with the aft end down. Prior to the second and final furnace cycle, which was accomplished at 1800 to 1825°F with the forward end down, Nioro braze alloy powder was applied at the forward flange.

(3) S/N's 27 and 28

The assembly and brazing procedures for S/N's 27 and 28 were the same as for S/N's 22 through 26 except for the following:

The tube leg thickness increased from a maximum of 0.014-in. to 0.016-in. The increased tube leg width resulted in a negative clearance for the shimming operation. The 0.001-in. thick braze alloy "U" foil configurations were removed from the shims and Nioro powder was applied between the shims and tube walls prior to the first braze cycle.

III. CONCLUSIONS AND RECOMMENDATIONS

III. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Successful chemical and nuclear firings have demonstrated the integrity of the NERVA U-Tube nozzles. NERVA nozzle S/N 9 sustained 404 seconds of operation (143 seconds at full power) during NRX-A2 firing; S/N 22 sustained 1513 seconds (979 seconds at full power) during NRX-A3 firings; S/N 21 sustained 227 seconds of chemical simulation firings. These test results confirm the basic design, and the assembly and furnace brazing procedures developed during this program.

The multiple braze cycle provides a high tube-to-tube fillet (sufficiently removed from the jacket) which acts as a heat sink and permits localized torch repair without excessive heat input. Acceptable localized repair procedures have been developed and successfully applied to subsequent nozzles incorporating three furnace braze cycles. Localized torch repair of gross leakage for nozzles S/N's 8 and 9 damaged the tubes and required excessive rework before this technique was developed.

Manufacturing tolerances of tube leg width, groove width, and contours influence the quality of the assembly. Tube leg width needs to be maintained to ± 0.0005 in. Groove width needs to be maintained to ± 0.001 in., and tube contour needs to be inspected in the free standing rather than restrained condition.

Application of duplex alloy overlays at potential leak areas and multiple furnace cycles is an acceptable method to prevent leakage on the NERVA U-Tube nozzles.

B. RECOMMENDATIONS

The following recommendations are intended for future designs:

The final acceptance criteria for the formed tube should include contour and dimensional requirements to be measured in the unrestrained condition.

The design and drawing requirements for tube leg widths should be reduced from ± 0.002 to 0.0005-in.

IV. REFERENCES

REFERENCES

1 - LRP Materials Engineering Dept. Report No. 61-01, K. L. Gustatson, Subject: Dry Hydrogen Furnace-Brazing of Titan II Combustion Chambers, dtd 7 Dec. 1961.

2 - Liquid Rocket Plant Materials Engineering Report No.63-210, NERVA "U" Tube Nozzle Design Concept Brazing Procedure Establishment, dtd 11 March 1963.

3 - Cauge, W. H., "Basic Characteristics of Source Heat Resisting Brazing Filler Materials," The Welding Journal, 35(a), Research Supply., 431-3-(1956).

4 - Chauge, W. H., "Further Evaluation of Ni-Cr-Band Au-18 Ni Brazing Alloys," The Welding Journal, Research Supply., 535-S-(1958).

5 - Marquardt Corp. Report No. 15087, Results of the Braze Development Program Conducted by the Marquardt Corporation for the NERVA Regeneratively Cooled Rocket Nozzle, Simulated Section No. 2 dtd 31 January 1964.

V. APPENDICES

APPENDIX A

HYDROTEST PROCEDURE FOR FULL LENGTH SECTORS

1. DETERMINE THAT ALL TOOLING TO BE USED IN THE FOLLOWING TESTS IS UNDAMAGED, CLEAN, COMPLETE AND INSPECTION UP TO DATE.

2. UNIT TO BE INSPECTED FOR DAMAGE PRIOR TO HYDRO TEST.

   NOTE: NOTIFY PROJECT PERSONNEL TO WITNESS TEST.

3. LEAK TEST

   (a) USING H_2O AS THE TEST MEDIA, PRESSURIZE THE TEST SAMPLE TO FIFTY(50) PSIG.

   (b) REAPIR ALL LEAKS FOUND AS REQUESTED BY PROJECT ENGINEER.

4. LEAK TEST: (REMOTE CONTROL)

   (a) USING H_2O AS THE TEST MEDIA, TEST AS FOLLOWS:

   (b) IN FIFTY (50) PSIG INCREMENTS PRESSURIZE TEST SAMPLE TO FIVE HUNDRED (500) PSIG.

   NOTE: LEAKAGE MAY OCCUR AT SOME PRESSURE: REDUCE PRESSURE TO FIFTY(50 PSIG TO LOCATE AND MARK LEAKS: REPAIRS TO BE MADE AS REQUIRED IN THE LABORATORY: THEN CONTINUE WITH PRESSURE SCHEDULE AS OUTLINED.

5. PROOF TEST:

   (a) USING H_2O AS THE TEST MEDIA: TEST AS FOLLOWS:

   (b) ADVANCE TO 1150 PSIG IN 100 PSIG INCREMENTS STARTING AT 550 PSIG.

   (c) HOLD AT EACH INCREMENT FOR TWO (2) MINUTES.

   (d) SHOULD LEAKS BE APPARENT DURING THIS TEST REPAIR AS REQUIRED BEFORE PROCEDING.

   NOTE: SHOULD FAILURE OCCUR DURING THIS TEST, REPAIR AND THEN REPEAT TEST SEQUENCE STARTING WITH OPERATION #3.

6. LEAK TEST:

   (a) USING H_2O AS THE TEST MEDIA: TEST AS FOLLOWS:

   (b) PRESSURIZE AT A RISE RATE OF 300 PSIG PER MINUTE MAXIMUM TO THE LEAK PRESSURE OF 860 PSIG.

   (c) HOLD TWO (2) MINUTES.

   (d) IF LEAKAGE IS APPARENT, LOCATE AND MARK LEAKS, REPAIR AS REQUIRED AND REPEAT TEST AND REPAIRS UNTIL NO LEAKS ARE EVIDENCED.

7. BURST TEST:

   (a) USING H_2O AS THE TEST MEDIA, TEST AS FOLLOWS:

   (b) STARTING AT 1150 PSIG INCREAS PRESSURE IN 100 PSIG INCREMENTS TO FAILURE OF TEST SAMPLE.

   (c) HOLD PRESSURE AT EACH STEP FOR ONE (1) MINUTE MINIMUM

   (d) DISPOSITION TO BE MADE BY PROJECT ENGINEER.

APPENDIX B

AEROJET-GENERAL CORPORATION
CODE IDENT. 05824

AGC-46590
18 September 1963

DEVELOPMENT PROCESS SPECIFICATION

CLEAN ROOM, FOR NERVA U-TUBE NOZZLE ASSEMBLY, SPECIAL REQUIREMENTS FOR

1. SCOPE

This specification establishes the minimum requirements for area cleanliness within the Nerva U-Tube Nozzle Assembly Area.

2. APPLICABLE DOCUMENTS

There are no applicable documents.

3. REQUIREMENTS

3.1 Design and construction.-

3.1.1 The clean room shall be air tight. The inside walls and ceiling of the room shall be coated with a smooth, tough, dust resistant material that will resist chipping, flaking, or powdering when subjected to normal contact with clean room personnel and equipment.

3.1.2 The lighting equipment shall provide shadowless uniform lighting at an intensity level of 100 - 150 ft-candles at bench level.

3.1.3 The clean room shall be capable of maintaining air pressure above that of adjacent areas. With all entry ways closed, the minimum positive pressure differential between the clean room and any adjacent area shall be 0.05 inches of water.

3.1.4 Entry-ways shall be double air lock type and shall provide an air seal sufficient to allow pressurization of the clean room.

3.1.5 Air supply and filtration equipment shall be provided and shall supply fresh or make-up air, as required. Prior to entering the room, all air shall receive adequate filtration to comply with the air cleanliness requirements specified herein. Air conditioning equipment, capable of cooling, heating, humidification or dehumidification shall also be provided as required for compliance with the temperature and humidity requirements specified herein.

3.2 Environment. -

3.2.1 Temperature. - The temperature shall be controlled from 67 to 77°F.

3.2.2 Humidity. - The humidity shall be controlled from 30 to 50 percent relative humidity.

3.3 Air cleanliness. - The number of particles in excess of 5.0 microns shall not exceed 700 per cubic foot.

3.4 Area control. -

3.4.1 Parts sent into the clean room area shall be stripped of all packaging materials except closures, intimate wrap or tote trays.

3.4.2 Clean, white smocks shall be worn by all personnel actively engaged in assembly or inspection operations within the area. The smocks shall not be in a tattered, frayed or torn condition during use.

3.4.3 Clean, white cotton gloves shall be worn by all personnel in the handling of parts. The gloves shall not be in a tattered, frayed or torn condition during use.

3.4.4 Smoking, eating or drinking shall not be permitted within the room.

3.5 Room content control. -

3.5.1 All bench tops shall be covered with stainless steel. In addition, neoprene mats may be used to protect critical part surfaces.

3.5.2 Bench tops used for assembly or inspecting parts shall be kept clean at all times.

3.5.3 Bin tops, cabinets, equipment, ceilings, overhead pipes, lights, etc. shall be kept clean to prevent the accumulation of dust or other gross contaminants.

3.5.4 Floors shall be kept clean at all times.

3.6 Processing.-

3.6.1 Line and filter openings shall be capped with clean closures of appropriate size and type when not in service. Part and assembly openings shall be similarly capped except when uncapped openings are necessary for fabrication purposes.

3.6.2 Storage in the clean room shall be limited to metal nozzle parts and metal assembly equipment.

3.6.3 Paper or paper-like toweling, used in contact with parts, shall be dirt and lint free.

4. QUALITY ASSURANCE PROVISIONS

4.1 General.- Adequate quality control shall be maintained in order to insure compliance with the requirements of this specification.

4.1.1 The room temperature and humidity shall be continuously recorded and shall be in accordance with Paragraphs 3.2.1 and 3.2.2 respectively.

Authorized for Release:

S. F. Lewinski, Supervisor
Engineering Specifications
Liquid Rocket Plant
Sacramento

/saj

APPENDIX C

REON

AGC-90006B
10 September 1965
Superseding
AGC-90006A
27 April 1965

SPECIFICATION

NOZZLE, U-TUBE, TUBE INSTALLATION
AND BRAZING PROCEDURE FOR (U)

CODE IDENT. NO. 05824

Sept.1965:7430:EL:hh

AEROJET GENERAL TIRE GENERAL

AGC-90006B
10 September 1965
Superseding
AGC-90006A
27 April 1965

CODE IDENT NO. 05824

SPECIFICATION

NOZZLE, U-TUBE, TUBE INSTALLATION
AND BRAZING PROCEDURE FOR

1. SCOPE

1.1 Scope.- This specification establishes the requirements for assembling and brazing the U-tube nozzle in accordance with the requirements and procedures stipulated herein and on the applicable Aerojet drawings.

2. APPLICABLE DOCUMENTS

2.1 NASA documents.- Unless otherwise specified, the following documents, of the issue in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

PUBLICATIONS

National Aeronautics and Space Administration

NPC 200-3	Inspection System Provisions for Suppliers of Space Materials, Parts, Components and Services.

(Application for copies should be addressed to the Superintendent of Documents, Government Printing Office, Washington 25, D.C.)

2.2 Aerojet-General Corporation documents.- Unless otherwise specified, the following documents, of the latest issue in effect, shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

AGC-44079	Brazing Alloy (Palniro-7:70 Au - 22 Ni - 8 Pd), High Temperature
AGC-44148	Brazing Alloy, Gold Nickel (Nioro: 82 Au - 18 Ni)
AGC-46350	Levels of Cleanliness, Description of
AGC-90022	Brazing Alloy (Nicoro 80: 81.5 Au-15.5 Cu-3.0 Ni)

Sept.1965:7430:EL:hh

AGC-90006B

STANDARD

AGC-STD-9001 Nozzle, U-tube, Cleaning and Protection of

REON Report No.

2487 REON Reliability and Quality Assurance Program Plan

3. REQUIREMENTS

3.1 Materials.-

3.1.1 Braze alloy.- The brazing alloys shall conform to Aerojet-General Corporation Specifications AGC-44079, AGC-44148 and AGC-90022 (see 2.2).

3.2 Cleanliness.- Prior to assembly, all nozzle components shall be cleaned as specified in Aerojet Standard AGC-STD-9001 (see 2.2).

3.3 Furnace equipment and performance.- Prior to and during any furnace brazing operations, the following requirements and procedures shall be met:

(a) The furnace chamber shall be vacuum purged to at least 28 inches of Hg (gauge) and back filled with argon five times prior to the introduction of the hydrogen atmosphere.
(b) All furnace brazing shall be accomplished in a protective hydrogen atmosphere. The hydrogen atmosphere at the inlet port shall have a dew point of -80°F or less and shall flow at a rate of at least 750 cubic feet per hour. The hydrogen inlet dew point shall be measured and recorded not less than one hour prior to furnace run.
(c) The part temperature recorder shall be capable of continuous monitoring and recording of part temperature with an accuracy of ± 10°F on at least six thermocouples which shall be attached to each assembly during brazing in accordance with figure 1.

3.4 Equipment required.- Equipment required shall be as follows:

(a) Dielectric foil positioning spacers
(b) Tube leg spacers
(c) Atmosphere manifolding
(d) Shim driving blanks
(e) Nozzle braze fixtures
(f) Handling and positioning carts
(g) Nozzle handling tool
(h) Resistance welding machines

3.5 Alloy application.- Prior to inserting the tubes into the jacket grooves, brazing alloy (AGC-44148) preforms conforming to the applicable drawings shall be placed into the grooves using dielectric foil positioning spacers. Using the dielectric foil spacers for locating purposes, AGC-44148 brazing alloy wires, 0.020 inch diameter, shall be tack resistance welded to each side of the grooves for the full length of the chamber. The tack welds shall not be more than 1.5 inches apart.

3.6 Assembly procedure.- The assembly procedure shall be as follows:

(a) The U-tubes are to be inserted into the jacket grooves, installed at the throat area, and progressively worked into the grooves to each end of the nozzle. A tube leg spacer is to be placed in the groove adjacent to the tube leg during resistance welding of the tube leg-to-jacket groove shear surfaces. Tube crown height gauges are to be used to maintain the applicable drawing dimensional requirements.

(b) Contoured shims are to be prepared for tube-to-tube insertion by resistance welding preformed AGC-44148 brazing alloy foil to the shim-to-tube faying surfaces.

(c) Shims are to be loacted and driven into place at the tube-to-tube joints using shim driving blanks. Shims are to be inserted circumferentially at each level. Start the shim installation process at the nozzle throat.

(d) AGC-44079 brazing alloy powder shall be applied to the upstream side of the tube-to-tube joints around the hot bleed port. An overlay of AGC-44148 powder is to be applied over the AGC-44079 fillet. Braze alloy powders shall be held in place with a mixture of acetone and Wall Colmonoy cement (or Aerojet approved equivalent).

3.7 Furnace brazing procedure.- During heat-up from 250° to 1725°F, the temperature deviations between metal parts shall not exceed 50°F. The parts temperature shall be stabilized at 1725 ± 10°F during heat-up for all furnace cycles. During cooldown, to 1100°F, the temperature deviations between metal parts shall not exceed 100°F. During cooldown, a protective atmosphere shall be maintained until part temperatur reaches 350°F or less.

3.7.1 First cycle.- The preassembled nozzle shall be placed on a leveled nozzle braze fixture that supports the pressure vessel flange, with the aft end down, and furnace brazed at 1825° to 1850°F for 5 to 10 minutes.

3.7.2 Second cycle.- This cycle shall be performed as follows:

(a) AGC-44079 brazing alloy powder is to be applied to all shim-to-shim joints and at the hot gas flow areas around the hot bleed port. Application vehicle is acetone. The filler fillet is to be feathered at both ends. Fillet length is to be 3/8 to 1/2 inch and height is not to exceed half the distance between the top of the shim and the tube crown. An overlay of AGC-44148 powder is to be applied over the AGC-44079 fillet. The vehicle is a mixture of acetone and Wall Colmonoy cement (or Aerojet approved equivalent). The ratio of AGC-44148 to AGC-44079 brazing alloy powder shall be one to one by weight. The appearance of the AGC-44148 overlay will show feathered ends and a total fillet length of 1/2 to 5/8 inch.

The total fillet shall be below the tube crown. Positioning carts are to be used to position surfaces horizontal during the application of the brazing alloy powders.

(b) The nozzle shall be placed on a leveled nozzle braze fixture that supports the pressure vessel flange with the forward end down, and furnace brazed at 1800° to 1825°F for 5 to 10 minutes.

3.7.3 Third cycle.- This cycle shall be performed as follows:

(a) AGC-90022 braze alloy powder shall be applied dry to all shim to tube joints. The amount of alloy applied shall not extend above the top of the shims. After application the powder shall be held in place by a mixture of acetone and Wall Colmonoy cement (or Aerojet approved equivalent).

(b) The nozzle shall be placed on a leveled nozzle braze fixture that supports the pressure vessel flange, with the forward end down, and furnace brazed at 1750° to 1775°F for 5 to 10 minutes.

3.8 Workmanship.- The workmanship and finish shall be of sufficiently high grade to insure satisfactory operation and durability consistent with the requirements of this specification.

4. QUALITY ASSURANCE PROVISIONS

4.1 Supplier responsibility.-

4.1.1 Inspection.- Unless otherwise specified, the supplier is responsible for all the inspection requirements as specified herein and may use any facility acceptable to Aerojet-General Corporation. Records of inspections, examinations and tests shall be kept complete and available to Aerojet as specified herein or in the contract or order. Continuous records of temperature and time shall be maintained for each furnace cycle.

4.2 Process approval.- A detailed processing procedure, including description of equipment, shall be submitted to Aerojet (REON) Engineering for approval and for coordination with AGC (REON) Product Assurance prior to the first part fabrication for each design and prior to any revision of the procedure.

4.3 NASA Publication NPC 200-3.- Quality assurance provisions shall be in accordance with the specific and applicable portions of NASA Quality Publication NPC 200-3 (see 2.1) as interpreted by REON Report No. 2487 (see 2.2).

4.4 Test procedures.-

4.4.1 Examination of product.- All tube-to-tube joints shall be visually inspected for a continuous line of brazing alloy.

4.4.2 Leak test.- Leak tests shall be performed in accordance with the applicable drawing.

4.4.3 Proof test.- Proof tests shall be performed in accordance with the applicable drawing.

5. PREPARATION FOR DELIVERY

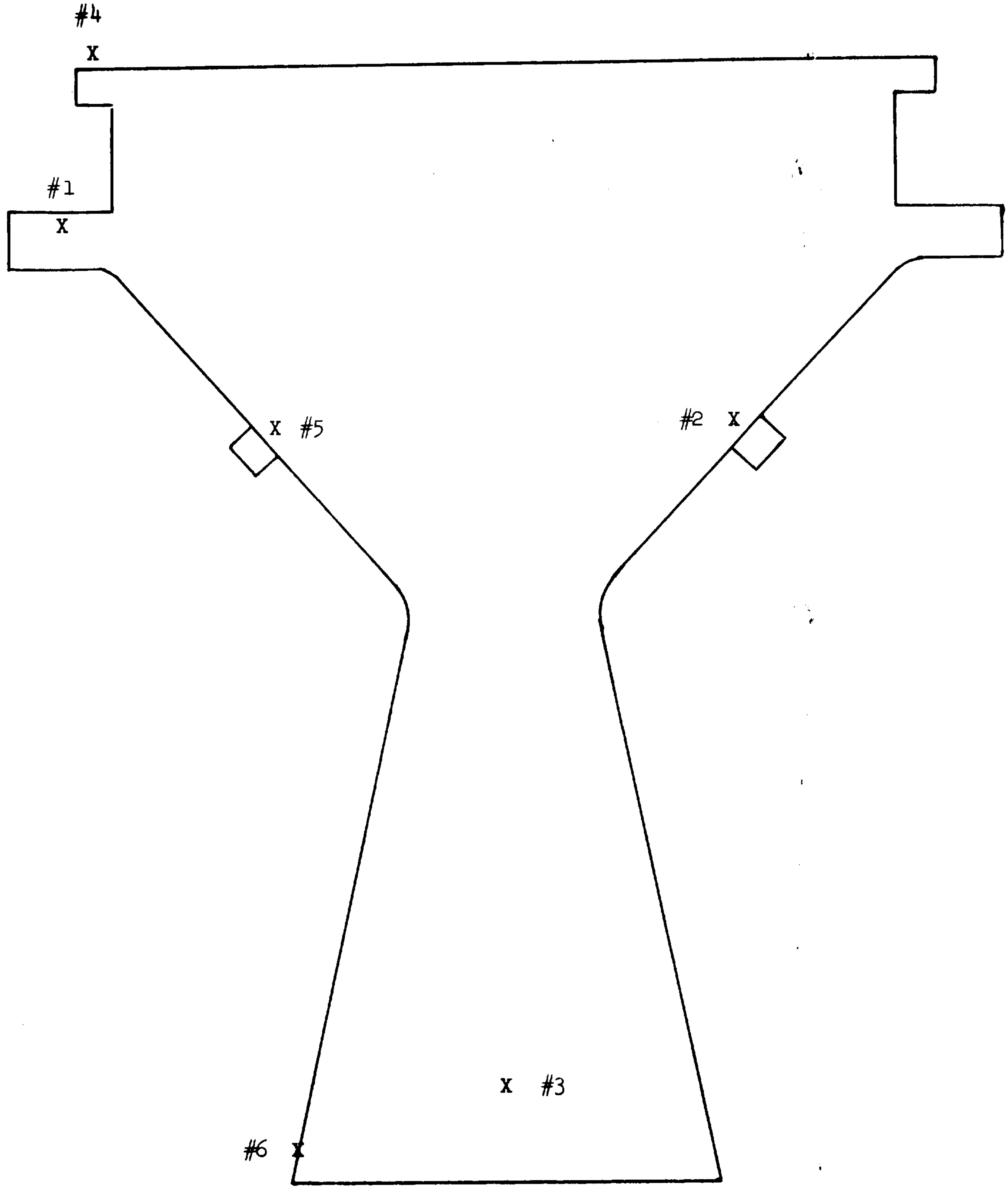
5.1 Preservation and packaging.- The nozzle shall be cushioned and protected as required to preclude damage during shipping, storage, and handling.

5.2 Marking.- Each container shall be suitably marked with the name, supplier and identifying number of the nozzle.

Authorized for Release:

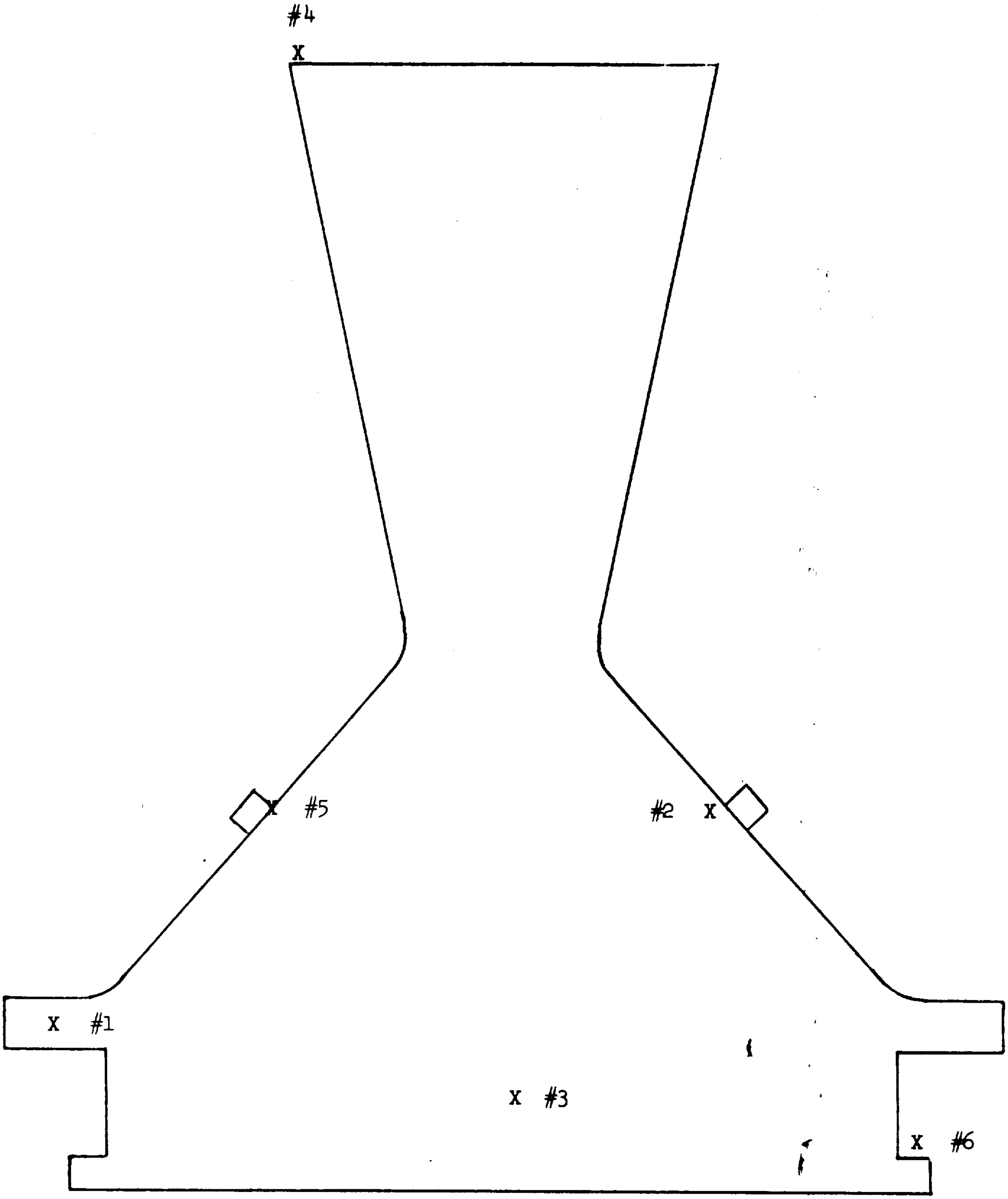
G A Boeck

G. A. Boeck
Technical Staff
Project Engineering Division - REON



FIRST BRAZE CYCLE
THERMOCOUPLE LOCATION

Figure 1(a



SECOND AND THIRD BRAZE CYCLE
THERMOCOUPLE LOCATION

Figure 1(b)

DOCUMENT APPROVAL
SIGNATURE SHEET

SPECIFICATION — AGC-90006B

Type of Document — Document Number

Title of Document NOZZLE, U-TUBE, TUBE INSTALLATION AND BRAZING PROCEDURE FOR

Document Prepared by E. Landesberg, Dept. 7430

Document Checked by H. W. Spaletta, Dept. 7416

APPROVAL SIGNATURE	DEPT.	DATE
[illegible]. L. Odgers, Manager Component Development Division - REON	7450	[illegible]-65
J. J. Beereboom, Manager Phoebus Division - REON	7500	9/1/65
C. R. Snyder, Manager [illegible] Chamber Dept. - REON	7450	[illegible]
R. [illegible] Murray, Manager Nozzle Design & Analysis, Phoebus - REON	7520	8-19-65
[illegible]. W. Funk, Manager Materials and Processes - REON	7416	8-19-65
G. S. Kaveney, Manager Structures - REON	7421	8-19-65
E. T. Kautt, Manager Analysis and Applied Research, Phoebus - REON	7510	8/20/65
W. A. Chapla, Manager Product Assurance Engineering - REON	7350	8-19-65
R. J. Squires, Manager Reliability & Quality Assurance, Phoebus - REON	7520	8-31-65
P. W. Rowe, Manager Project Engineering Division - REON	7430	8-31-65

Sept.1965:7430:EL:hh

APPENDIX D

Pyromet 104
dtd. 10 November 1964
Enclosure (1)

PROCEDURE FOR ASSEMBLY OF NERVA U-TUBE CHAMBER AT PYROMET, INC., SAN CARLOS, CALIFORNIA

1. All components shall be unpackaged and visually examined for damage and/or surface defects.

2. Dimensionally inspect forward and aft chamber lands. Record dimensions.

   AGC Inspection ____________________

3. Dimensionally inspect internal tube widths adjacent to end caps. Record Dimensions.

   AGC Inspection ____________________

4. Clean room contamination level is to conform to AGC Spec. 46590 and to Pyromet rules and procedure governing its use before any components are transferred to it for subsequent assembly.

   Employees engaged in assembly work are to use supplied clean room attire, to observe rules governing procedures and rules governing their methods and conduct.

   AGC Inspection ____________________

5. Alloy application shall be in accordance with AGC 90006, Paragraph 3.6.

6. The U-Tubes are to be inserted into the jacket grooves.

7. Resistance tack weld coolant channel leg to groove wall at locations indicated ~~per~~ drawing 707630 and specification AGC 90006

8. After each work shift, visually inspect the seating of channel to the bottom of groove, as observed through the "scalloped" opening.

   AGC Inspection ____________________

9. Inspect coolant channel shims for dimensional and material conformance, visually inspect for burrs and state of cleanliness.

   AGC Inspection ____________________

10. Shims are to be prepared in accordance with AGC 90006, Paragraph 3.7 (b).

    AGC Inspection ____________________

11. Shims are to be located and driven into place at the Tube-to-Tube joints using shim driving blanks. Shims are to be inserted circumferentially at each level before progressing to the next level.

12. Visually inspect nozzle for uniformity of crown heights at the throat.

AGC Inspection ______________________

13. Tube end caps and thermocouple bosses shall be "Tig" welded to the nozzle per AGC Spec. 46351 B.

14. Make final check of assembly in prebraze condition:

    a. All components are in position.
    b. Braze alloy is applied as required.

15. Inspect and record throat OD and ID at 6 places, 30° invervals. Establish inspection points.

AGC Inspection ______________________

16. Remove assembled nozzle from clean room and transport to the furnace area. Protect internal nozzle surfaces from contamination during exposure to Shop Area.

17. Position the nozzle on the furnace base on brazing fixture No. T-604284, exit end down. Be certain assembly is leveled in the fixture.

    a. Check positioning on base.
    b. Place atmosphere manifold over pressure vessel end and weld in place.
    c. Check manifold installation. Bonds are to be adequate and flanges of pressure vessel and manifold to evidence no gaps between mating surfaces.
    d. Install copper pipe from base inlet to fitting on atmosphere manifold.
    e. Place heat shield plate over pressure vessel end.
    f. Install thermocouples per attached sketch.
    g. Place upper retort to 30 inch Hg minimum. Back fill with argon each time. Repeat this cycle 4 times. Evacuate the retort a fifth time on this final cycle, back fill with dry hydrogen (-80F or better). Check hydrogen dewpoint for conformance to AGC 90006, Paragraph 3. 3 (b). Begin hydrogen flow into the retort at the rate of 1000 cubic feet per hour.

18. Place cold furnace bell over retort (500F or lower).

19. Begin heating of retort. Keep temperature spread between thermocouples to no more than 50F. Continue to control temperature as above from ambient temperature to 1725F.

20. When parts temperature reaches 1725F, increase furnace control settings to maximum rate of climb regardless of thermocouple spread at this temperature plateau until parts temperature reaches 1825 to 1850F. When lowest thermocouple reaches 1825F, start soak or holding time of five minutes.

21. At the end of the 5 minute interval, disconnect power to the furnace and cool as rapidly as possible to 1725F.

22. Set furnace controls so that cooling rate decline from 1725F to 1100F does not allow a thermocouple temperature spread in excess of 100F.

23. When load temperature reaches 1100F, the furnace bell may be removed and the retort and its load allowed to air cool without control.

24. When assembly reaches 350F or lower, the retort is to be purged with exothermic gas.

25. Remove heat shield, atmosphere manifold, copper atmosphere line and thermocouples from the assembly.

26. Check furnace and assembly for general effect of atmosphere and evidence of alloy run off.

27. Move nozzle to clean room and apply powdered alloy in accordance with AGC 90006, Paragraph 3.8.2.(a).

28. Remove nozzle from clean room and transport to the furnace area. Protect internal nozzle surfaces from contamination during exposure to Shop Area.

29. Position assembly on the furnace base and AGC Tool No. 604216. Be certain assembly is level on brazing tool. With forward or pressure vessel end downward. Install atmosphere manifold.

30. Connect copper pipe from furnace base atmosphere inlet to fitting on manifold.

31. Place heat shield over manifold.

32. Install 6 load thermocouples per sketch.

33. Check position on base.

34. Install upper retort section and seal in place.

35. a. Vacuum purge retort to 30 inch Hg minimum, back fill with argon, repeat this cycle 4 times.
    b. Vacuum purge 5th time, back fill with dry hydrogen (-80F dewpoint or better). Check hydrogen dewpoint for conformance to AGC Spec. 90006, Paragraph 3.3 (b).
    c. Begin hydrogen flow into the retort at the rate of 1000 cubic feet per hour.

36. Place furnace bell over retort (500F or lower).

37. Begin heating of retort. Keep temperature spread indicated by load thermocouples to no more than 50F. Continue to control to this range until parts temperature reaches 1725F. Stabilize temperature at this plateau point.

38. Increase temperature at maximum rate of thermal climb without regard to thermocouple spread until parts temperature reaches 1800 to 1825F. When lowest couple reaches 1800F, start soak or holding time of 5 minutes.

39. At end of 5 minute heat soak interval, shut off furnace power and cool as rapidly as possible to 1725F.

40. When lowest couple reaches 1725F, control the temperature decline from 1725F to 1100F to allow no greater parts temperature spread than 100F.

41. When highest thermocouple reaches 1100F, the furnace bell may be removed and the temperature allowed to decline without regard to thermal spread.

42. When highest indicated temperature reaches 350F or lower, purge chamber with exothermic gas and open retort.

43. Check general appearance of assembly and interior of retort.

44. Remove assembly from brazing fixture and move to the clean room.

45. Dimensionally inspect and record throat OD and ID at 6 places. See Operation (15).

AGC Inspection ______________________

46. Visually inspect and record entire assembly for:

    a. Continuity of braze joints.
    b. Uniformity of crown heights at the throat.
    c. Dents or damages to tubes.

AGC Inspection ______________________

47. Package in AGC supplied container for shipment to Aerojet-Sacramento.

48. Third braze cycle procedure:

49. Move nozzle to clean room and apply powdered alloy - Nicoro 80 - to all tube-to-tube joints (entire length).

50. Cement in place with Wall Colmonoy cement.

51. Remove nozzle from clean room and transport to the furnace area. Protect internal nozzle surfaces from contamination during exposure to Shop Area.

52. Position assembly on the furnace base and AGC Tool No. 604216. Be certain assembly is level on brazing tool with forward or pressure vessel end downward. Install atmosphere manifold.

53. Connect copper pipe from furnace base atmosphere inlet to fitting on manifold.

54. Place heat shield over manifold.

55. Install 6 load thermocouples per sketch.

56. Check position on base.

57. Install upper retort section and seal in place.

58. a. Vacuum purge retort to 30 inch Hg minimum, back fill with argon, repeat this cycle 4 times.
    b. Vacuum purge 5th time, back fill with dry hydrogen (-80F dewpoint or better). Check hydrogen dewpoint for conformance to AGC Spec. 90006, Paragraph 3. 3 (b).
    c. Begin hydrogen flow into the retort at the rate of 1000 cubic feet per hour.

59. Place furnace bell over retort (500F or lower).

60. Begin heating of retort. Keep temperature spread indicated by load thermocouples to no more than 50F. Continue to control to this range until parts temperature reaches 1650F. Stabilize temperature at this plateau point.

61. Increase temperature at maximum rate of thermal climb without regard to thermocouple spread until parts temperature reaches 1750 to 1775F. When lowest couple reaches 1750F, start soak or holding time of 5 minutes.

62. At end of 5 minute heat soak interval, shut off furnace power and cool as rapidly as possible to 1650F.

63. When lowest couple reaches 1650F, control the temperature decline from 1650F to 1100F to allow no greater parts temperature spread than 100F.

64. When highest thermocouple reaches 1100F, the furnace bell may be removed and the temperature allowed to decline without regard to thermal spread.

65. When highest indicated temperature reaches 350F or lower, purge chamber with exothermic gas and open retort.

66. Check general appearance of assembly and interior of retort.

67. Remove assembly from brazing fixture and move to the clean room.

68. Dimensionally inspect and record throat OD and ID at 6 places. See Operation (15).

AGC Inspection ______________________

69. Visually inspect and record entire assembly for:

    a. Continuity of braze joints.
    b. Uniformity of crown heights at the throat.
    c. Dents or damages to tubes.

AGC Inspection ______________________

70. Package in AGC supplied container for shipment to Aerojet-Sacramento.

APPENDIX E

AEROJET-GENERAL CORPORATION

CODE IDENT. 05824

AGC-46601A
20 May 1964

Superseding
AGC-46601
25 October 1963

PROCESS SPECIFICATION

NOZZLES, U-TUBE, TUBE INSTALLATION AND BRAZING PROCEDURE FOR

1. SCOPE

1.1 This specification establishes the requirements for assembling and brazing Nerva U-tube nozzles in accordance with AGC Drawing 285946.

2. APPLICABLE DOCUMENTS

2.1 Other documents.- Unless otherwise specified, the following documents, of the issue in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

Society of Automotive Engineers

AMS 4775	Brazing Alloy, Nickel Base - 4Si - 16.5 Cr - 4Fe - 3.8B
AMS 4777	Brazing Alloy, Nickel Base - 4Si - 7 Cr - 3Fe - 3B
AMS 5782	Steel Wire, Corrosion and Heat Resistant - 19Cr - 9 Ni - 1.5V - 0.5 Mo - 0.2 Ti

2.2 Aerojet-General Corporation documents.- Unless otherwise specified, the following documents, of the latest issue in effect, shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

AGC-44148	Brazing Alloy
AGC-46004	Degreasing, Hot Vapor Method Of
AGC-46350	Levels of Cleanliness, Description Of

STANDARD

AGC-STD-4833	300 Series Stainless Steel, Cleaning and Passivating Of

DRAWING

285946	Jacket, Tube Coolant

3. REQUIREMENTS

3.1 Materials.-

3.1.1 Braze alloy.- The brazing alloy shall conform to Specification AGC-44148.

3.1.2 Metallic grit.- All grit blasting shall be performed using -80 + 120 mesh AMS 4775 or AMS 4777 metallic grit.

3.2 Cleanliness.- Prior to assembly, the nozzle shell shall be vapor degreased per Specification AGC-46004 and subjected to a hot alkaline and HNO_3-HF solution per AGC-STD-4833. All part surfaces shall conform to the level H requirements of Specification AGC-46350. After cleaning, the nozzle shell shall be protected from contamination by placing the nozzle in a clean sealed plastic enclosure. Clean white dacron gloves shall be used when handling the shell and tubes prior to packaging.

3.3 Furnace equipment and performance. - Prior to and during any furnace brazing operations, the following capabilities and procedures shall be in evidence.

3.3.1 The furnace chamber shall be vacuum purged to at least 28 inches of Hg (gauge) and back filled with argon five times prior to the introduction of the hydrogen atmosphere.

3.3.2 All furnace brazing shall be accomplished in a protective hydrogen atmosphere. The hydrogen atmosphere at the inlet port shall have a dew point of -80°F or less and shall flow at a rate of at least 750 cubic feet per hour.

3.3.3 The part temperature recorder shall be capable of continuous part temperature monitoring and recording. At least six thermocouples shall be attached to each assembly during brazing.

3.3.4 During heat-up above 250°F the temperature deviations between metal parts shall not exceed 50°F.

3.3.5 The parts temperature shall be stabilized at 1725 ± 10°F.

3.3.6 During cool-down, to 1100°F, the temperature deviations between metal parts shall not exceed 100°F.

3.3.7 During cool-down, a protective atmosphere shall be maintained to at least 350°F.

3.4 Surface preparation. - The following grit blasting procedure, using AMS 4775 or AMS 4777 grit, shall be performed prior to brazing.

3.4.1 Insert the U-tubes into the appropriate grit blasting tool fixture and protect the inside surfaces of the tubes during the blasting operation with a formed RTV 60 silicon rubber core. Grit blast the tube-to-tube and tube-to-jacket faying surfaces until all exposed areas have a light frosted appearance. The tubes should not be allowed to twist or bend during this operation.

3.4.2 After grit blasting, all components shall be handled with white dacron gloves.

3.5 Alloy application. - Prior to inserting the tubes into the jacket grooves, braze alloy (AGC-44148) wire, 0.020 inch in diameter, shall be resistance tack welded the full length of the chamber on each side of the grooves. The tacks shall be no more than 1.5 inches apart. Additional wire alloy shall be applied on each side of the grooves as follows:

(a) The upper flange end extending three inches toward the downstream end.
(b) Alloy wires three inches in length at the 4.687 radius area.
(c) Alloy wires three inches in length at the 3.971 radius area.
(d) Alloy wires three inches in length at the 4.65 reference dimension.
(e) Alloy wires three inches in length at the 16.25 reference dimension.

3.6 Assembly procedure. -

3.6.1 The notch at the forward end of each tube shall be selectively filed to fit under the forward nozzle flange. The U-tubes shall be inserted into the jacket grooves, installed under the forward flange, and progressively worked into the grooves to the exit end of the nozzle. A 0.022 inch spacer tool shall be placed in the groove adjacent to the tube leg during resistance welding of the tube leg-to-jacket groove shear surfaces. Gage blocks and center alignment tooling shall be used to maintain the applicable drawing dimensional requirements.

3.6.2 Contoured shims shall be prepared for tube-to-tube insertion by resistance welding preformed AGC-46148 braze alloy foil (0.001 x 0.625 x 4.00 ± .10 inches) to the shim-to-tube faying surfaces.

3.6.3 Shims shall be located and driven into place at the tube-to-tube joints using expendable driving blanks. All shims shall be inserted circumferentially at each level while progressing from the forward flange to the exit end of the nozzle.

3.6.4 The tube end caps shall be TIG welded to the jacket using weld wire per AMS 5782.

3.6.5 The thermocouple bosses shall be selectively cut to length and TIG welded using weld wire per AMS 5782.

3.7 Furnace brazing procedure.-

3.7.1 First cycle.- The preassembled nozzle shall be placed on a leveled ring fixture that supports the pressure vessel flange, with the outlet end down, and furnace brazed at 1825 - 1850°F for 5-10 minutes.

3.7.2 Second cycle.-

3.7.2.1 Braze alloy powder (AGC-44148, -150 mesh size) shall be applied to the tube-to-forward flange faying surfaces and to shim-to-shim joints where visual examination reveals lack of complete coverage during the first cycle.

3.7.2.2 The nozzle shall be placed on a leveled ring fixture, that supports the pressure vessel flange with the inlet end down, and furnace brazed at 1800-1825°F for 5-10 minutes.

4. QUALITY ASSURANCE PROVISIONS

4.1 Process approval.- A detailed processing procedure shall be submitted to AGC Engineering for approval prior to the first part fabrication and prior to any revision of the procedure.

4.2 Inspection criteria.-

4.2.1 Examination of product.- All tube-to-tube and tube-to-flange joints shall be visually inspected for a continuous line of braze alloy.

4.2.2 X-ray examination.- All tubes shall be subjected to X-ray examination to determine the extent of tube blockage.

4.3 Leak test.- Leak tests shall be performed in accordance with the applicable drawing.

4.4 Proof test.- Proof tests shall be performed in accordance with the applicable drawing.

4.5 Records.- Continuous records of temperature, and time shall be maintained for each furnace cycle.

Authorized for Release:

S. F. Lewinski, Supervisor
Engineering Specifications
Liquid Rocket Operations
Sacramento

/lg
/saj